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RESEARCH MEMORANDUM

STABILITY RESULTS OBTAINED WITH DOUGLAS D-558-1 AIRPLANE (BuAero No. 37971) IN FLIGHT UP TO A MACH NUMBER OF 0.89

By

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Measurements have been made of some of the high-speed characteristics of the D-558-1 airplane up to a Mach number of 0.89. The results of these tests showed that the stabilizer incidence drastically affected the longitudinal trim characteristics above a Mach number of 0.80. With a stabilizer incidence of 2.3°, the airplane became nose heavy above a Mach number of 0.8. With a stabilizer incidence of 1.4°, the airplane became tail heavy above a Mach number of 0.83. The airplane also became right-wing heavy above a Mach number of 0.84 and the airplane felt uncertain laterally to the pilot. The longitudinal stability in accelerated flight was positive throughout the speed range from a Mach number of 0.50 to 0.80 and increased above a Mach number of 0.675. The buffet boundary was defined up to a Mach number of 0.84 and was similar to that for the Bell XS-1 airplane with the same wing section, 65-110.

INTRODUCTION

The NACA is engaged in a flight-research program in the transonic-speed range utilizing Douglas D-558-1 type airplanes which were procured for use by the NACA in high-speed flight. One of these airplanes (BuAero No. 37971) was being used for investigation of stability and control characteristics. This airplane was lost in an accident on May 3, 1948. Up to the time of the accident, two reports covering some measurements of longitudinal stability (reference 1) and measurements of the stability characteristics in sideslips (reference 2) had been published. This paper presents some of the more pertinent high-speed results obtained prior to the accident which were not reported in references 1 or 2.

SYMBOLS

H	pressure altitude, feet
M'	Mach number uncorrected for position error

M	Mach number corrected for position error
ΔM	Mach number error (M-M')
n	normal acceleration, g units
f_e	elevator force, pounds
δ_e	elevator position, degrees from stabilizer
δ_a	total aileron angle, difference in degrees between left and right aileron
δ_r	rudder position, degrees from neutral position with respect to fin
β	sideslip angle, degrees from arbitrary reference (approx. parallel to center line of airplane)
i_t	stabilizer setting, degrees from fuselage level line
C_N	normal-force coefficient (Wn/qS)
q	dynamic pressure, pounds per square foot
W	airplane gross weight, pounds
S	wing area, square feet

AIRPLANE

The Douglas D-558-1 airplane is a single-place low-wing monoplane powered by a General Electric TG-180 turbojet engine. General views of the airplane are given in figures 1(a), 1(b), and 1(c). A three-view drawing of the airplane is given in figure 2. Detailed specifications of the airplane are given in reference 1.

The force required to move the wheel controls slowly under static airplane conditions is shown in figure 3. The rudder friction is of the order of 7 pounds near neutral position. The elevator control has a bungee tending to return the elevator to the down position. All controls have hydraulic dampers at the control surface which necessitate high control force for rapid motion of control.

INSTRUMENTATION

Standard NACA recording instruments were used to measure the various quantities necessary to determine the stability and control characteristics of the subject airplane. All records were synchronized by means of a common timing circuit. The instruments used and the quantities measured follow:

Recording instrument	Quantity measured
Airspeed-altitude recorder	Indicated airspeed, pressure altitude
Three-component accelerometer	Normal, longitudinal, and transverse acceleration
Angular-velocity recorder	Rolling velocity
Yaw-angle recorder	Sideslip angle
Wheel-force recorder	Aileron and elevator force
Pedal-force recorder	Rudder-pedal force
Control-position recorder	Aileron, elevator, rudder, and stabilizer position
Timer	Time

The yaw vane used with the yaw-angle recorder was mounted a distance of 1 chord ahead of the left wing tip. The airspeed head was mounted on a boom on the right wing tip of such length that the static orifices were at a distance of 1 chord ahead of the wing leading edge.

TESTS, RESULTS, AND DISCUSSION

A calibration of the airspeed system was made using the fly-by and radar tracking methods of reference 3. The results of the calibration are presented in figure 4 as a variation of percentage error in Mach number $\frac{\Delta M}{M}$, with corrected Mach number. The error increases above $M = 0.75$ due to blocking effects of the wing on static pressure at the airspeed head. These results are in general agreement with data obtained from a similar airspeed installation on the Bell XS-1 airplane, reference 4.

The stability measurements reported here were obtained for the most part from two high-speed runs to a Mach number of approximately 0.89 and several turns made at various Mach numbers up to 0.81. Time histories of the two high-speed runs made at altitudes of about 40,000 feet are given in figures 5 and 6. In the run shown in figure 5, the pilot used a stabilizer setting of 2.3°; in the run shown in figure 6, a stabilizer setting of 1.4° was used. As shown in figure 5, the airplane with a 2.3° stabilizer setting became increasingly nose heavy as the Mach number was increased above 0.80. During the initial phase of the recovery, (after 50 sec) an appreciable pull force was required to increase the normal-force coefficient and decrease the Mach number. As the Mach number decreased (time, 60 sec), the nose heaviness also decreased and the pilot was required to relieve the pull force to prevent reaching high values of acceleration. With the 1.4° stabilizer setting in figure 6 the airplane became increasingly tail heavy above a Mach number of 0.83. During the recovery in this run (65 to 89 sec and $M = 0.88$ to 0.834) the pilot merely decreased the push force and a normal recovery was effected. The pilot reported that in both runs, there was buffeting which began at about a Mach number of 0.85. It is also interesting to note that above a Mach number of 0.84, the airplane becomes very right-wing heavy and the pilot applied control to correct it. The pilot reported that this wing heaviness was not continuous and it was difficult to determine the lateral control required for trim. As a consequence, the airplane felt uncertain laterally at the highest speeds as can be seen by the control motions used by the pilot, and the lateral oscillations which resulted. Some of this uncertainty in lateral trim may arise from aileron friction. (See fig. 3.)

In order to illustrate further the control required by the pilot to trim the airplane, control positions and forces and sideslip angle for steady flight were selected from figures 5 and 6 and plotted in figure 7 as functions of Mach number. In this figure, the difference in control required for trim caused by the two stabilizer settings is clearly shown. These trim changes, from the standpoint of pilot's forces, are large in that approximately 30 pounds force was required in either the pull or push direction, depending on the stabilizer setting. In the case of the Bell XS-1, data for two stabilizer settings showed no difference in the direction of the trim change as the airplane becomes nose heavy in both cases (reference 4) for this Mach number range. The right-wing heaviness is illustrated in this figure by the increased left aileron for trim required at the higher speeds. There was no appreciable change in rudder position or sideslip angle. (A similar phenomenon of wing heaviness was noted with the XS-1 airplane (reference 4).)

Some stability and control data in accelerated flight were obtained from steadily increasing turns made at an altitude of 30,000 feet in a Mach number range from 0.50 to 0.80 and one turn made at 10,000 feet at a Mach number of 0.71. The results of these measurements are given in figure 8 where the stick force per g and elevator angle required per unit C_N are plotted as functions of Mach number. These data show that the longitudinal stability is positive throughout the speed range and is lowest at about a Mach number of 0.675. Above a Mach number of 0.675, the stability increases with increasing Mach number. These results are in general agreement with the data obtained on the Bell XS-1 airplane (reference 5). Although data were available only at one speed for an altitude of 10,000 feet, it is interesting to note that the apparent stability is higher at 10,000 feet than at 30,000 feet. Some of this difference can be accounted for by the effect of altitude but it is also possible that, because of the higher dynamic pressure at the lower altitudes, the apparent stability is altered by distortion effects.

The buffet boundary for the D-558-1 airplane has been determined from straight stalls, turns, and high-speed runs. The results of these measurements are given in figure 9 where the normal-force coefficients necessary for buffeting are plotted as functions of Mach number. The buffet boundary as presented in this figure defines the combination of Mach number and normal-force coefficient where buffeting begins. Below a Mach number of 0.70, the airplane was flown into the buffet boundary and the test points shown beyond the boundary represent maximum lift for a gradual maneuver at the test speed. Above a Mach number of 0.70, the airplane was flown into the buffet region but peak lift was not obtained during the tests. For comparison, the buffet boundary for the Bell XS-1 airplane with the same wing section 65-110 (references 4 and 6) is also shown in this figure. As might be expected, the buffet boundaries for the two airplanes are quite similar.

CONCLUSIONS

Data obtained in flight up to a Mach number of 0.89 with the D-558-1 airplane showed the following:

1. With a stabilizer incidence of 2.3°, a longitudinal trim change in the nose-down direction was experienced above a Mach number of 0.80. With a stabilizer setting of 1.4°, a longitudinal trim change in the nose-up direction was experienced above a Mach number of 0.83.

2. The airplane becomes right-wing heavy above a Mach number of 0.84. This lateral disturbance is such that the airplane and control feel very uncertain to the pilot.

3. The longitudinal stability in accelerated flight was positive from a Mach number of 0.50 to 0.80 and increased above a Mach number of 0.675.

4. The buffet boundary was determined up to a Mach number of 0.84 and is similar to that for the Bell XS-1 airplane with the same 65-110 wing section.

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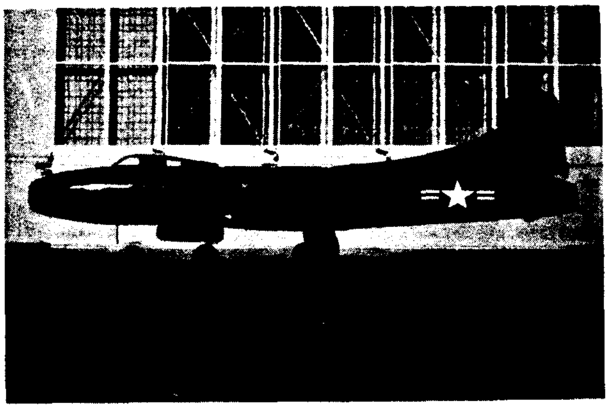
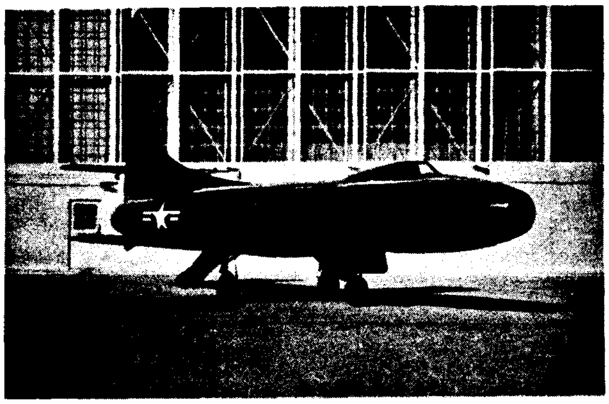
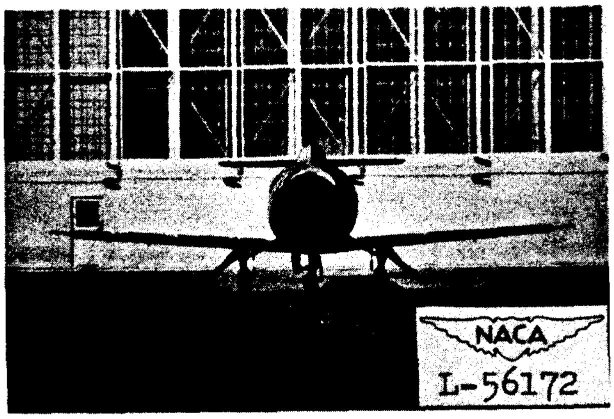


(a) Side view.



(b) Three-quarter front view.



(c) Front view.

Figure 1.- Photographs of D-558-1 airplane.

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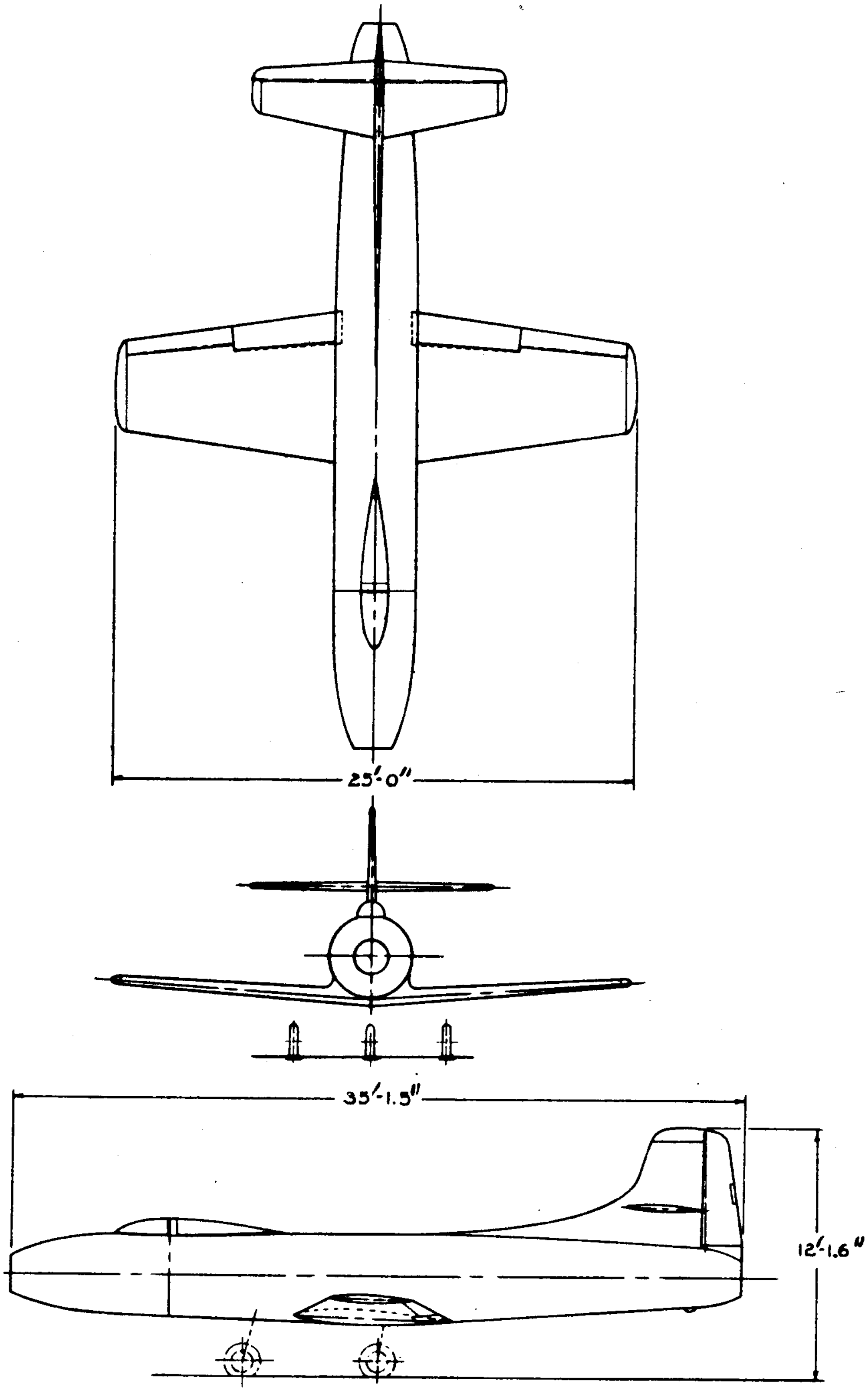

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Figure 2.- Three-view drawing of D-558-1 airplane.

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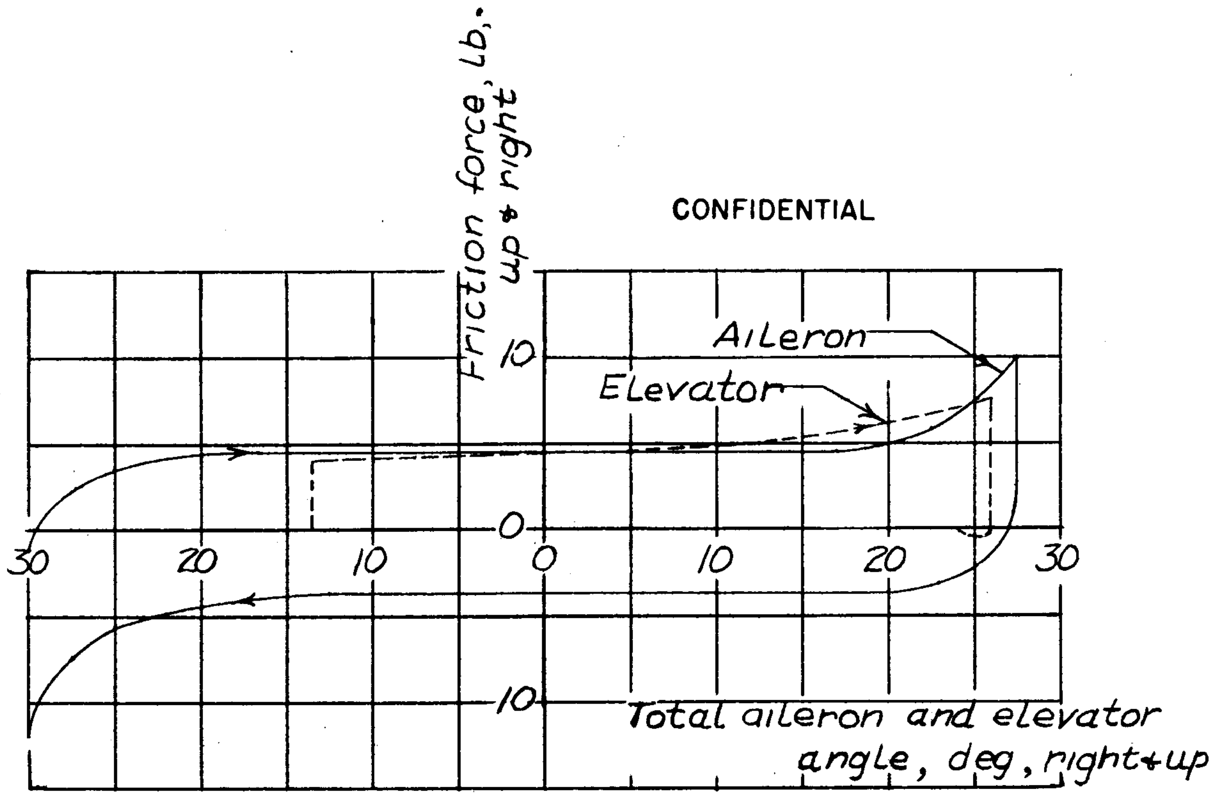

Figure 3.– Control friction forces obtained by moving controls slowly in direction shown. D-558-1 airplane.

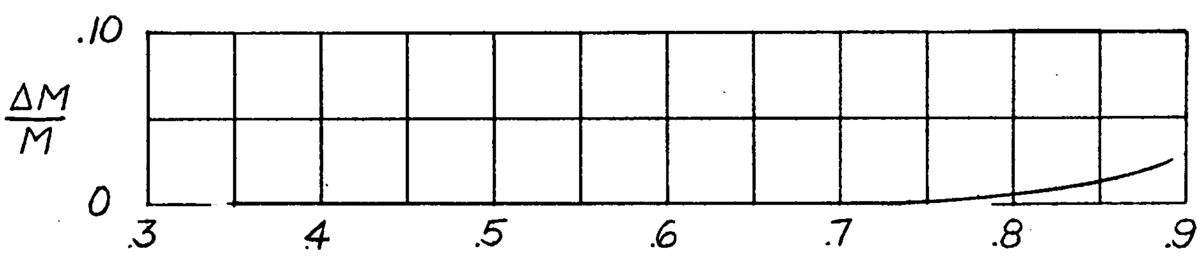

Figure 4.– Variation of percentage error in Mach number, $\frac{\Delta M}{M}$, with corrected Mach number.

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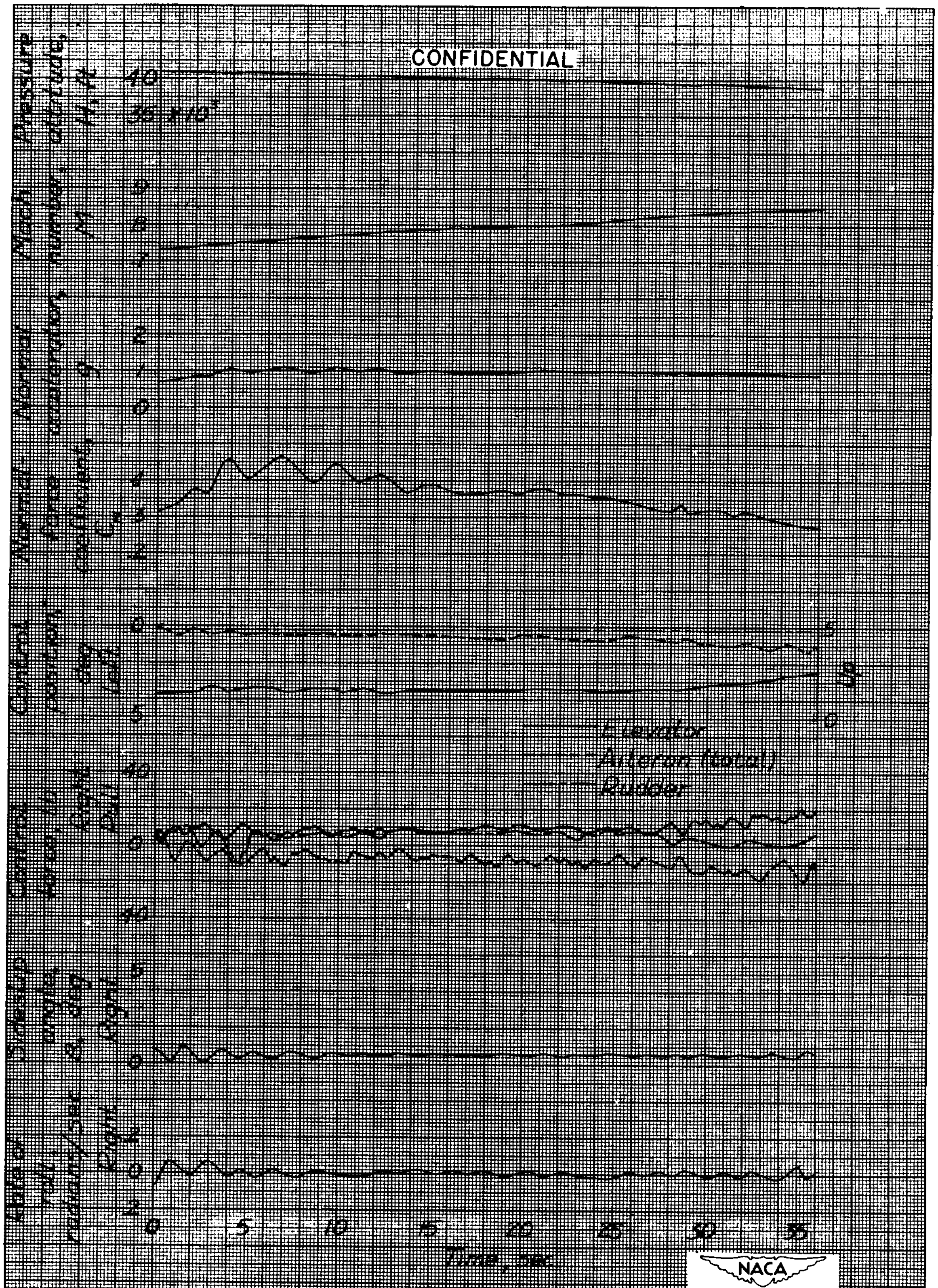

Figure 5.- Time history of measured quantities during high-speed run. D-558-1 airplane. $i_t = 2.3°$

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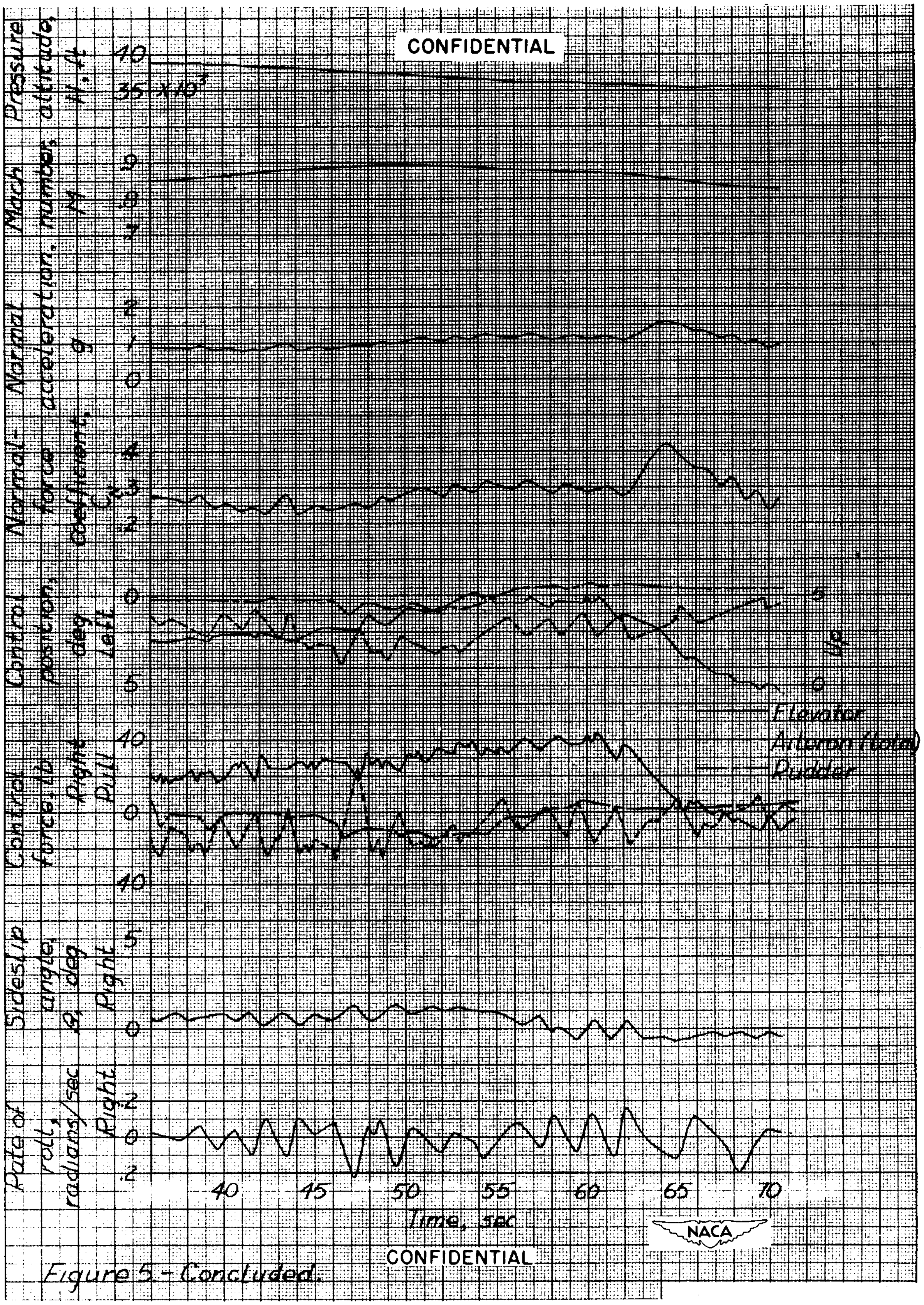

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Figure 5.- Concluded.

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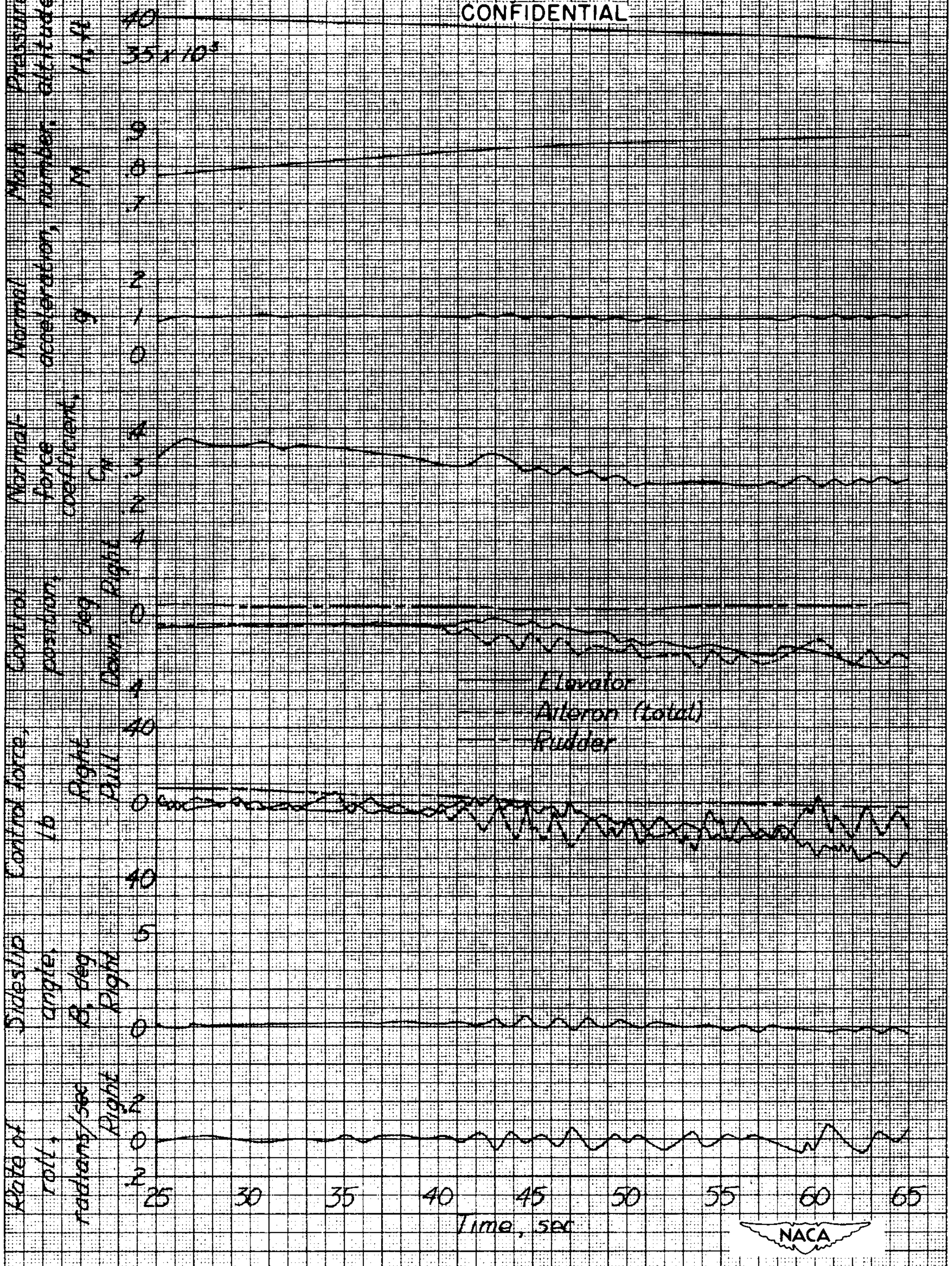

Figure 6 – Time history of measured quantities during high-speed run. D-558-1 airplane. $i_t = 1.4°$

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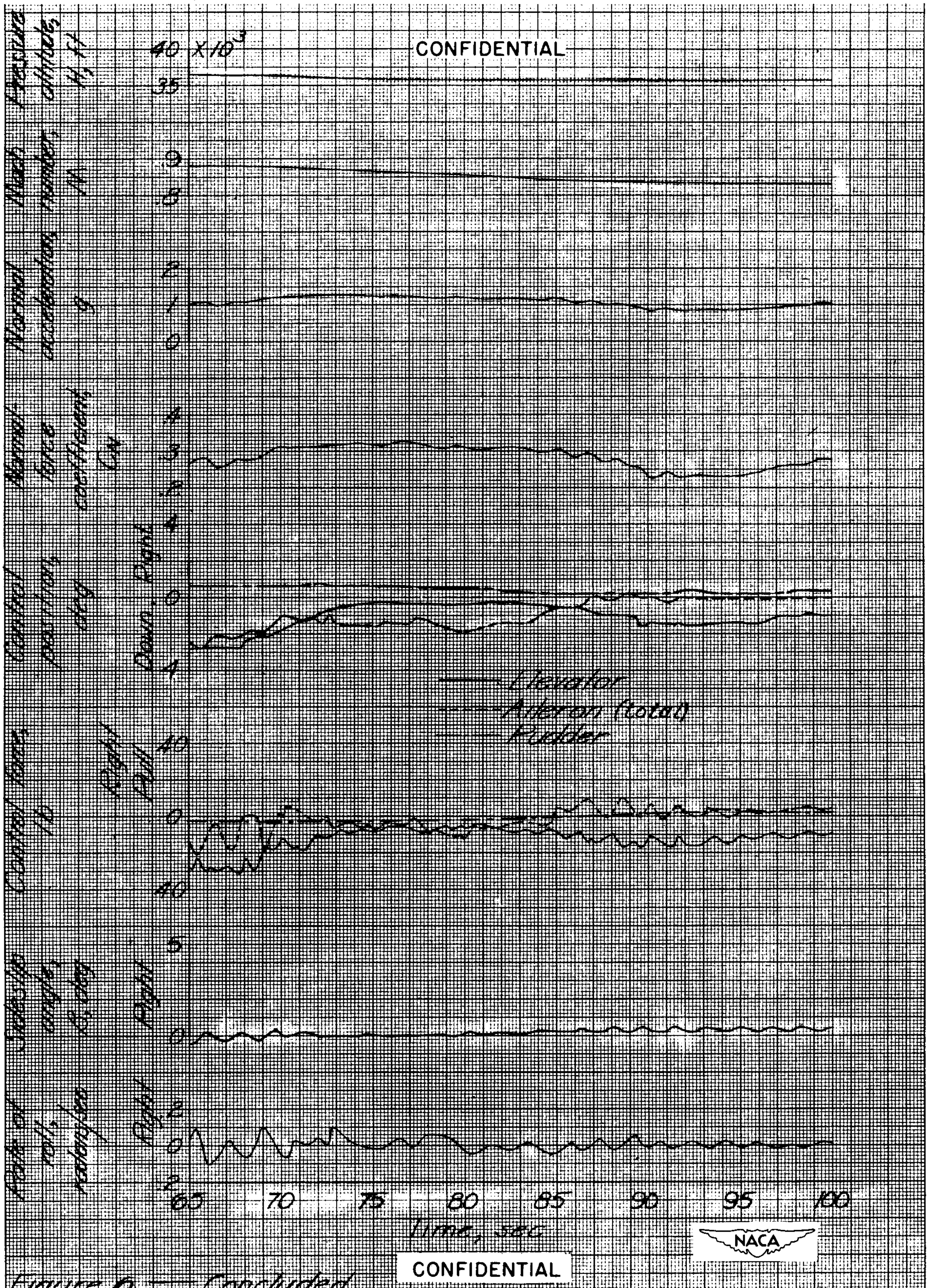

Figure 6.— Concluded.

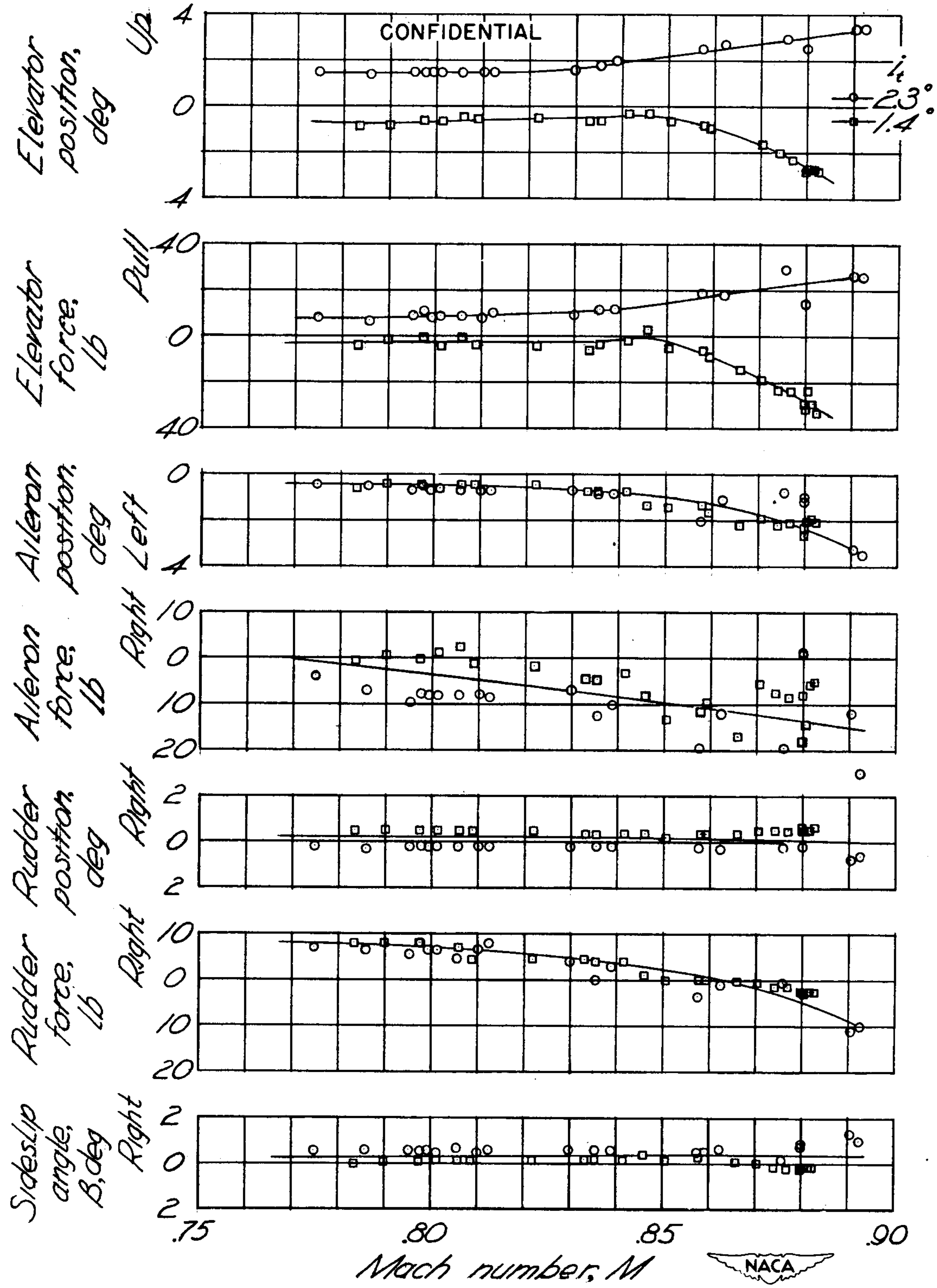

Figure 7.- Variation of airplane trim forces and positions with Mach number. ($C_N \approx .23$ to $.43$) D-558-1 airplane.

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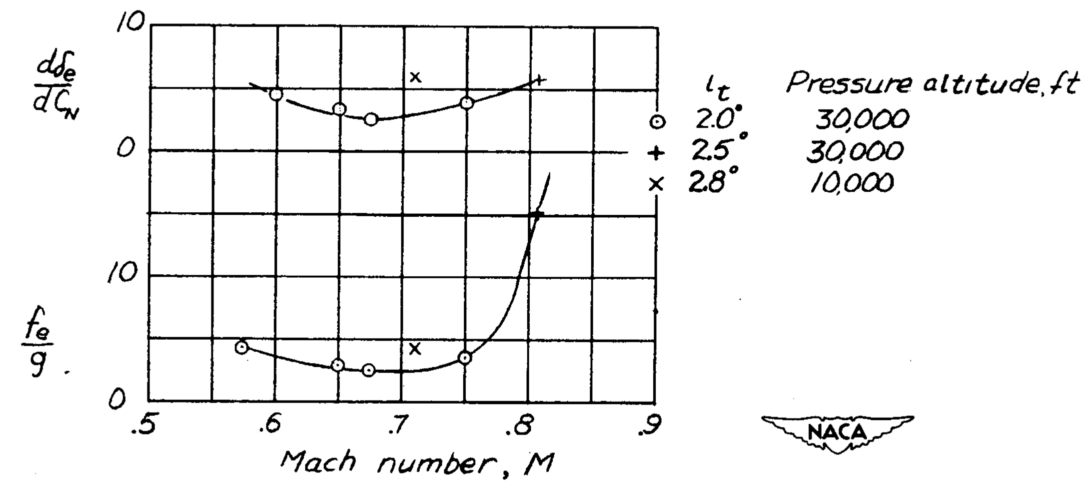

Figure 8.- The variation of stick force per g, f_e/g, and the change in elevator angle per unit C_N, $d\delta_e/dC_N$, with Mach number. D-558-1 airplane.

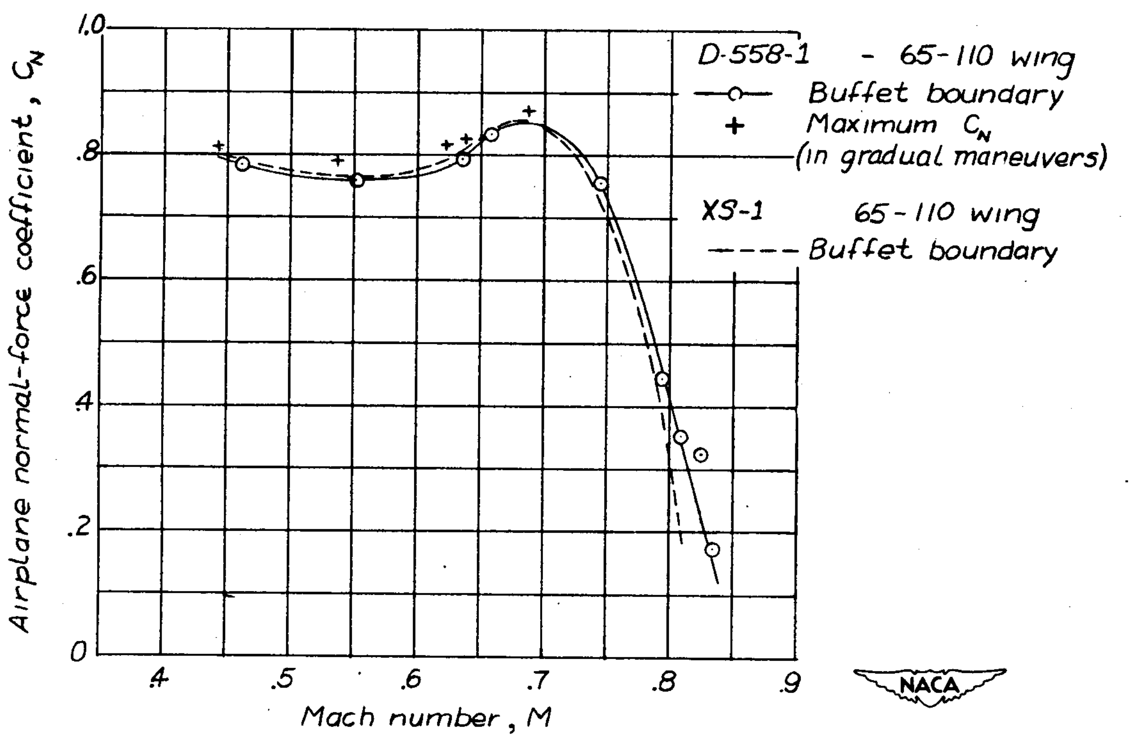

Figure 9.— Buffet boundary of D-558-1 airplane compared with buffet boundary of XS-1 airplane.

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RESEARCH MEMORANDUM

RESULTS OF MEASUREMENTS MADE DURING THE APPROACH AND

LANDING OF SEVEN HIGH-SPEED RESEARCH AIRPLANES

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WASHINGTON
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

RESULTS OF MEASUREMENTS MADE DURING THE APPROACH AND LANDING OF SEVEN HIGH-SPEED RESEARCH AIRPLANES

By Wendell H. Stillwell

SUMMARY

An investigation has been conducted by the National Advisory Committee for Aeronautics of the landing characteristics of the X-1, X-3, and D-558-I straight-wing, the X-4, X-5, and D-558-II swept-wing, and the XF-92A delta-wing high-speed research airplanes. These tests have shown that ground contact occurs at about 70 to 90 percent of the maximum normal-force coefficient even though the maximum normal-force coefficient was established by maximum lift, stability or control limitations, or ground clearance restrictions. The average vertical velocity at ground contact for the normal landings was about 2 feet per second and the maximum vertical velocity was about 4.6 feet per second.

Tests of the X-4 airplane to determine the effect of lift-drag ratio on the landing maneuver showed that the largest portion of the landing flare was made at altitudes above 50 feet at low lift-drag ratios and that, although the vertical velocities during the approach varied from 30 to 90 feet per second, the vertical velocities at contact were less than 5.5 feet per second.

INTRODUCTION

The trend in design of airplanes for transonic and supersonic flight is toward the use of wings with thin sections, low aspect ratios, sweep, and high wing loadings. Considerable interest has, therefore, been evidenced in the effects of high vertical velocities resulting from the low lift-drag ratios and high stalling speeds of such designs on the pilots' ability to perform the landing maneuver in a safe and accurate manner.

An analysis of the effects of low lift-drag ratios and high stalling speeds on the landing-flare characteristics (ref. 1) indicated that the excess speed ratio required at the start of the flare increased considerably as the lift-drag ratio decreased and that the flare will have to

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start at relatively high altitudes. Also, previous flight experience with the landing maneuver (ref. 2) has indicated that landings in which the vertical velocity at the start of the landing flare exceeded a value of about 25 feet per second demanded great piloting skill and were not regarded as practical maneuvers.

In order to provide data concerning the landing maneuver with airplanes exhibiting some of the above characteristics an investigation of the landing characteristics of high-speed airplanes has been undertaken at the NACA High-Speed Flight Station at Edwards, Calif. The investigation included average landings of the X-1, X-3, X-4, X-5, D-558-I, D-558-II, and XF-92A airplanes and landings of the X-4 at various lift-drag ratios. This paper has been prepared to report the results of this investigation.

SYMBOLS

b	wing span, ft
c	wing chord, ft
c_r	root chord, in.
c_t	tip chord, in.
C_N	normal-force coefficient, nW/qS
g	acceleration due to gravity, ft/sec^2
L/D	lift-drag ratio
n	normal acceleration, g units
q	dynamic pressure, $\frac{1}{2}\rho V^2$, lb/sq ft
S	wing area, sq ft
V	true airspeed, ft/sec
V_i	indicated airspeed, mph

W weight, lb

ρ density, slugs/cu ft

Subscript:

max maximum

DESCRIPTION OF AIRPLANES

A three-view drawing of each test airplane is shown in figure 1. Complete descriptions of each test airplane are contained in references 3 to 9 and some of the dimensions and characteristics pertinent to this investigation are contained in table I.

INSTRUMENTATION

Standard NACA recording instruments were installed in each airplane and although the instrumentation was not identical, the following quantities pertinent to this investigation were recorded for each airplane:

- Airspeed
- Altitude
- Vertical, longitudinal, and transverse acceleration at the center of gravity
- Control positions

Ground equipment was used to determine airplane flight path during the approach and landing. This equipment consisted of a modified SCR 584 radar phototheodolite and a modified Askania KTH - 41 phototheodolite. The radar phototheodolite was used to record airplane altitude and position with respect to the radar station and from this information the flight path during landings was determined. The flight path and vertical velocity during the flare were obtained from data recorded by the Askania phototheodolite located approximately one mile from the end of the runway and approximately one-half mile from the edge of the runway. Radar beacons were used to synchronize the Askania camera and test airplane recorders with the radar station.

TESTS, RESULTS, AND DISCUSSION

Normal Landings

The normal landings of the X-1, X-3, XF-92A, D-558-I, and D-558-II airplanes were made on the dry lake at Edwards, Calif. Runways 300 feet wide and from $4\frac{1}{2}$ to 7 miles in length were marked on the dry lake surface. The landings of the X-4 and X-5 were normally made on a 300- by 8,100-foot paved runway.

Landings of the X-1, X-4, X-5, D-558-I, and D-558-II airplanes were performed by three NACA research pilots. Landings of the XF-92A were performed by two Air Force test pilots during the Air Force evaluation program and by one NACA pilot during the NACA tests. The landings of the X-3 were performed by a company test pilot during the manfacturers' demonstration program. All of these pilots have considerable experience in flight tests of high-speed aircraft.

The landing data were obtained during regular research flights and with the exception of the tests of the X-4 at various lift-drag ratios, specific flights to obtain landing data were not made. The pilots were aware that landing data were being obtained but no instructions or restrictions were given to the pilots concerning the landing maneuver. All landings were made where there was excessive runway length and are not considered maximum performance landings. Winds were usually low in relation to flight speeds and are believed to have had no appreciable effect on the landing maneuvers.

The patterns of some airplanes show large variations between landings, but these variations are considered normal if the variations did not result from difficulties encountered during the maneuver and the pilot described it as a normal maneuver. The data presented herein, except as noted, are therefore believed to represent normal or average landing maneuvers.

The recording instruments were normally started when the airplane was on the downwind leg approximately opposite the contact point. The flight paths are presented as the projected plan and side view of the landing maneuver with initial ground contact as the reference point. The indicated airspeeds in miles per hour are noted at approximately the downwind, crosswind, and initial ground contact points.

As used in this paper $C_{N_{max}}$ is defined as the maximum normal-force coefficient that an airplane can attain in the landing maneuver and may be established by the angle of attack at which the tail cone contacts the ground or by the C_N at which stability or control characteristics prevent the airplane from being flown at a higher C_N or from the actual C_N of the airplane at stalling speed.

X-1.- Figure 2(a) shows the flight path during three landings of the X-1 airplane. The X-1, being a glider, makes the initial turn at high altitude so that excess altitude is available to be used as power and, if necessary, this excess altitude is lost during turns and slips on the final approach. The approach is made at an indicated airspeed of approximately 200 to 220 miles per hour and contact occurs between 130 and 150 miles per hour, indicated airspeed, which corresponds to 70 to 95 percent of $C_{N_{max}}$ for stall.

Difficulty was experienced in landing the X-1 as a result of a large change in longitudinal trim and light control forces at stalling speeds. This large variation in trim made it difficult to perform a smooth, controlled landing without inadvertently skipping into the air several times. The landing of this airplane is also complicated by very poor pilot visibility at moderate angles of attack.

X-3.- Figure 2(b) shows three landing patterns of the X-3 airplane. These landings are of particular interest because the high wing loading of the X-3 results in landings at speeds that are considerably faster than other research airplanes. The first landing of this airplane is represented in figure 2(b) by the solid line and shows the large approach turn and long straight-in approach (about 10 miles) used with the X-3. Considerable power was maintained during the approach and although airspeeds were not recorded during this landing the pilot reported contact at about 240 miles per hour, indicated airspeed.

The second landing is represented by the dotted line and illustrates a problem that may be encountered because of unfamiliarity with the maneuvering characteristics of an airplane with a high wing loading. This landing was started from a position of almost two miles to the side of the runway, and although the approach turn was made at normal-force coefficients of from 50 to 60 percent of $C_{N_{max}}$, the airplane had completed only about 90° of turn when the runway was crossed and therefore considerable overshoot was encountered. This landing maneuver could not have been completed had not a fairly long approach (approximately five miles) been available to correct for the overshoot of the turn.

The third landing shown has a very large approach turn and is representative of the later landings of the X-3 airplane.

The minimum landing speed of the X-3 is restricted because of limited tail cone clearance and C_N for tail cone contact occurs at about 80 percent of C_N for stall. Contact speeds have been at an indicated airspeed of about 250 miles per hour which corresponds to about 70 percent of the C_N for tail cone contact. Vertical velocities of less than 4 feet per second have been encountered at ground contact.

X-4.- Figure 2(c) shows normal landing patterns for the X-4 airplane. The approach speeds were generally higher than for the other airplanes, except for the X-3, varying from 220 to 250 miles per hour, indicated airspeed. Contact occurred at from 150 to 165 miles per hour, indicated airspeed, which corresponds to 70 to 80 percent of $C_{N_{max}}$. Engine power is reduced gradually during the approach turn and partial power is sometimes carried to ground contact.

With the landing gear down the minimum speed of the X-4 corresponding to $C_{N_{max}}$ with the elevons in the full-up position occurs at an indicated airspeed of about 135 miles per hour. Were it not for the high landing speed caused by the ineffective longitudinal control the pilots would consider the X-4 a very satisfactory airplane to land.

The X-4 is equipped with large effective dive brakes and therefore a powerful control of the glide path is available to the pilot. The approach is usually made with from 10° to 20° of dive brake deflection and after the flare is completed the dive brakes are opened to 60° at the desired landing point and the airplane immediately settles to the runway.

X-5.- Presented in figure 2(d) are three landings of the X-5 airplane at a wing sweep angle of 20°. The approach speeds varied from 170 to 180 miles per hour, indicated airspeed, and contact occurred at 115 to 130 miles per hour, indicated airspeed. The approach and contact speeds are lower than the other research airplanes, being comparable with present-day fighter-type jet aircraft. Landings at lower speeds would be possible with the X-5 were it not for the poor directional stability at speeds below an indicated airspeed of approximately 110 miles per hour. Contact occurs at about 85 percent of the C_N corresponding to the minimum speed of 110 miles per hour.

Operation of the speed brakes on the X-5 produces a large trim change and extreme buffeting. Consequently they are not used during the landing maneuver.

D-558-I.- The flight path during one landing of the D-558-I is presented in figure 2(e). Although additional landing data are not available, this landing is believed to be representative of the D-558-I landings. The approach was made at 210 miles per hour, indicated airspeed, and contact at 143 miles per hour which corresponds to approximately 70 percent of $C_{N_{max}}$ for stall. Power was carried until the airplane was at about the 90° position and as desired the speed brakes were used to aid in glide path control. Although the D-558-I has good control characteristics near the stall, it exhibits an abrupt roll-off at the stall and therefore pilots land with an appreciable speed margin above the stall. At these speeds the D-558-I is felt by pilots to have no objectionable characteristics in the landing maneuver.

D-558-II.- Presented in figure 2(f) are the flight paths during landings of the rocket–jet-powered and rocket-powered D-558-II airplanes. These airplanes are identical except for the lack of a jet engine in the rocket-powered airplane which must therefore perform the landing as a glider. Inboard wing fences were on both airplanes during these tests. The landings of each airplane were started from about the same position to the side of the runway, but the glider airplane had from 3,000 to 8,000 feet more altitude at this point.

As with the X-1, the glider D-558-II used up excess altitude in turns and slips on the final approach. Speed brakes provided additional aid in controlling the glide path for both airplanes. The D-558-II exhibits poor dynamic lateral stability with the flaps down at speeds above about 200 miles per hour, indicated airspeed (ref. 8). Therefore, some pilots prefer not to extend the flaps during the approach until the speed decreases below 200 miles per hour. The approach speeds were from 220 to 240 miles per hour, indicated airspeed, and the contact airspeed was about 140 miles per hour for the glider and from 5 to 10 miles per hour faster for the powered airplane.

The minimum landing speed of the D-558-II is restricted because the tail cone hits the ground when the airplane is in the landing attitude at speeds below 130 miles per hour, which corresponds to a C_N of about 80 percent of $C_{N_{max}}$. In addition, at 140 miles per hour and below, the D-558-II becomes neutrally stable longitudinally and difficulty is encountered when making landings near this speed. Normal landings with both airplanes were made at 80 to 85 percent of the C_N for 130 miles per hour.

XF-92A.- Three landings of the XF-92A are presented in figure 2(g). These landings were started from about the same position, and the landing patterns are similar to those of the X-5 and D-558-I. High engine power settings were maintained during most of the downwind leg and approach turn and power was reduced slowly on the final approach. The minimum landing speed is restricted to an indicated airspeed of approximately

140 miles per hour because of the limited tail cone clearance which occurs at a C_N of about 60 percent of the C_N for stall. The approach is made at approximately 230 miles per hour, indicated airspeed, and contact at 180 to 153 miles per hour which corresponds to 70 to 80 percent of the C_N at tail cone contact.

Presented in figure 2(h) are three landings of the XF-92A that are of interest for comparison with figure 2(g). These landings were made at about the same approach and contact speeds as those of figure 2(g), but they were made at idle engine power and therefore at lower lift-drag ratios. The landing patterns of figures 2(g) and 2(h) are similar except for a higher initial altitude and higher altitude at the start of the flare for the landings at idle engine power. Ground effect on the XF-92A was noticeable to the pilots and probably contributed greatly to the fact that the vertical velocities at ground contact were approximately the same for the landings with power on and at idle power. It is of interest to point out that one landing of the XF-92A, not recorded, was made dead stick and the pilot reported no significant difference from the landings at idle power.

Vertical Velocities at Ground Contact

Shown in figure 3 are the vertical and horizontal velocities at the initial ground contact point for landings of the test airplanes. The horizontal velocities represent ground speeds under wind conditions that were generally less than 15 to 20 feet per second. The average vertical velocity is about 2 feet per second and a vertical velocity of 4.6 feet per second was the largest encountered during these normal landings. It is interesting to point out that significant differences between the vertical velocities of the D-558-II glider and jet-powered airplanes or between the power-on or idle power landings of the XF-92A airplane are not apparent.

Ground Effect

With short landing gear and low aspect ratios the cushioning of ground effect is very pronounced and is one factor tending to decrease the vertical velocities at contact. Although quantitative data concerning ground effect were not obtained during this investigation, the pilots reported it is noticeable on the X-1, D-558-I, and D-558-II although not as pronounced as on the X-4 and XF-92A airplanes. Ground effect has been very noticeable on the XF-92A and landings have been described by some pilots as being easily accomplished by maintaining a constant glide angle and utilizing the ground effect to reduce the vertical velocity to a low value near the ground.

Effects of Lift-Drag Ratio

During the landing tests of the X-4 it was decided that because of the wide range of lift-drag ratios available by use of the large dive brakes, an investigation would be conducted of the effects of lift-drag ratio on the landing maneuver.

Figure 4 shows the variation of lift-drag ratio with dive-brake angle and indicated airspeed for the X-4 airplane. These lift-drag ratios were measured in gliding flight with the jet engines throttled back to produce zero thrust. This figure shows that lift-drag ratios between 1.5 to 6.0 may be obtained during the approach and from about 3 to 9.5 at contact.

Figure 5 shows a comparison of the landing patterns of the X-4 with values of lift-drag ratio at the beginning of the approach varying from 8 to 3.5. These landings were started at an altitude of approximately 3,000 feet with the engines maintaining zero thrust and with a constant dive-brake angle during the landing maneuver. The patterns become smaller as the lift-drag ratio decreases which requires an increase in acceleration during the approach turn from 1.1g at a lift-drag ratio of 8 to about 1.5g at a lift-drag ratio of 3.5. The higher acceleration results also from the fact that part of the landing flare is made during the final approach turn at the lower lift-drag ratios. This has prevented landings from being made at dive-brake settings greater than 35° because the largest portion of the flare is made during the turn at these settings and there is insufficient elevon control to enable the maneuver to be accomplished at larger dive-brake settings. One factor noted by the pilots was the short length of time, 50 seconds, at an approach lift-drag ratio of 3.5 as compared with about 140 seconds at a lift-drag ratio of 8 during which the pilot could correct and modify his landing approach.

The poor longitudinal control at large dive-brake settings was the pilots' greatest complaint during these flights. They felt that, if sufficient longitudinal control were available, landings could be performed at still lower lift-drag ratios. Landings at the lowest lift-drag ratios were not felt to require exceptional piloting skill or a great deal of practice. However, it should be remembered that for these landings the lift-drag ratio increased with decreasing speed and although landings were started at a lift-drag ratio of 3.5 the lowest lift-drag ratio at contact was about 6.2 even neglecting ground effect. At high lift-drag ratios ground effect was very noticeable to the pilots, whereas at the lower lift-drag ratios ground effect was not nearly so pronounced.

A comparison of the patterns for normal landings of the X-4 with these landings shows that the normal landings have a pattern similar to that obtained at a lift-drag ratio of 8. The pilots indicated, however, that, if they had to make landings with fixed dive brakes, an approach lift-drag ratio of about 5 would be preferable. Although no attempt to obtain spot landings has been made, it is the opinion of the pilots that greater accuracy is possible at the lower values of lift-drag ratios.

The vertical velocity at the beginning of the approach, at an altitude of 50 feet, and at contact are presented in figure 6 for various lift-drag ratios. The approach vertical velocities vary from about 90 feet per second at a lift-drag ratio of 3.5 to about 30 feet per second at a lift-drag ratio of about 9.0. The vertical velocity at 50 feet, however, has a value of from 25 to 10 feet per second and shows little variation with lift-drag ratio indicating that, at the lower lift-drag ratios, a greater part of the flare is performed at altitudes above 50 feet. The vertical velocities at contact were below a value of 3 feet per second at lift-drag ratios from about 11 to 7 and increased slightly to values of 3.5 and 5.5 feet per second at lift-drag ratios near 6.0.

CONCLUDING REMARKS

Tests of the X-1, X-3, X-4, X-5, D-558-I, D-558-II, and XF-92A airplanes have shown that ground contact occurs at about 70 to 90 percent of the maximum normal-force coefficient even though the maximum normal-force coefficient was established by maximum lift, stability or control limitations, or ground clearance restrictions. The average vertical velocity at ground contact for the normal landings was about 2 feet per second and the maximum vertical velocity was about 4.6 feet per second.

Landings of the X-4 airplane to determine the effect of lift-drag ratio showed that the largest portion of the landing flare was made at altitudes above 50 feet at low lift-drag ratios and that, although the vertical velocities during the approach varied from 30 to 90 feet per second, the vertical velocities at contact were less than 5.5 feet per second.

High-Speed Flight Station,
National Advisory Committee for Aeronautics,
Edwards, Calif., November 5, 1954.

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TABLE I

DIMENSIONS AND CHARACTERISTICS OF TEST AIRPLANES

Airplane		X-1 glider	X-3		X-4	X-5	D-558-I	D-558-II	XF-92A
Wing sweep angle, deg		0 at 0.40c	0 at 0.75c		41.57 at L.E.	20 at 0.25c	0 at 0.25c	35 at 0.30c	60 at L.E.
Wing area, sq ft		130	166.5		200	167	150	175	425
Aspect ratio		6	3.09		3.6	6.09	4.17	3.57	2.31
Wing loading, lb/sq ft (landing)		56	115		33	49	63	Glider, 53 Jet, 55	30
Flaps	Type	Plain	Split T.E.	Plain L.E.	None	Split	Split	Plain	None
	Span	0.40b	0.45b	0.70b	-------	0.41b	0.55b	0.35b	-----
	Chord	0.20c	0.25c	12.5 in.	-------	c_r=30.8 in. c_t=19.2 in.	0.20c	0.20c	-----
	Travel	60°	50°	30°	-------	60°	50°	50°	-----
Slats	Span	None	-----	None	None	0.65b	None	0.56b	None
	Chord	-----	-----	--------	-------	c_r=11.1 in. c_t=6.6 in.	-----	8.6 in.	-----
Speed brakes	Location or type	None	Bottom forward fuselage		Split flap	Forward fuselage	Aft fuselage	Aft fuselage	None
	Area, sq ft	-----	10.5		33.4	6.25	5	5.25	-----
	Travel	-----	50°		±60°	60°	60°	60°	-----

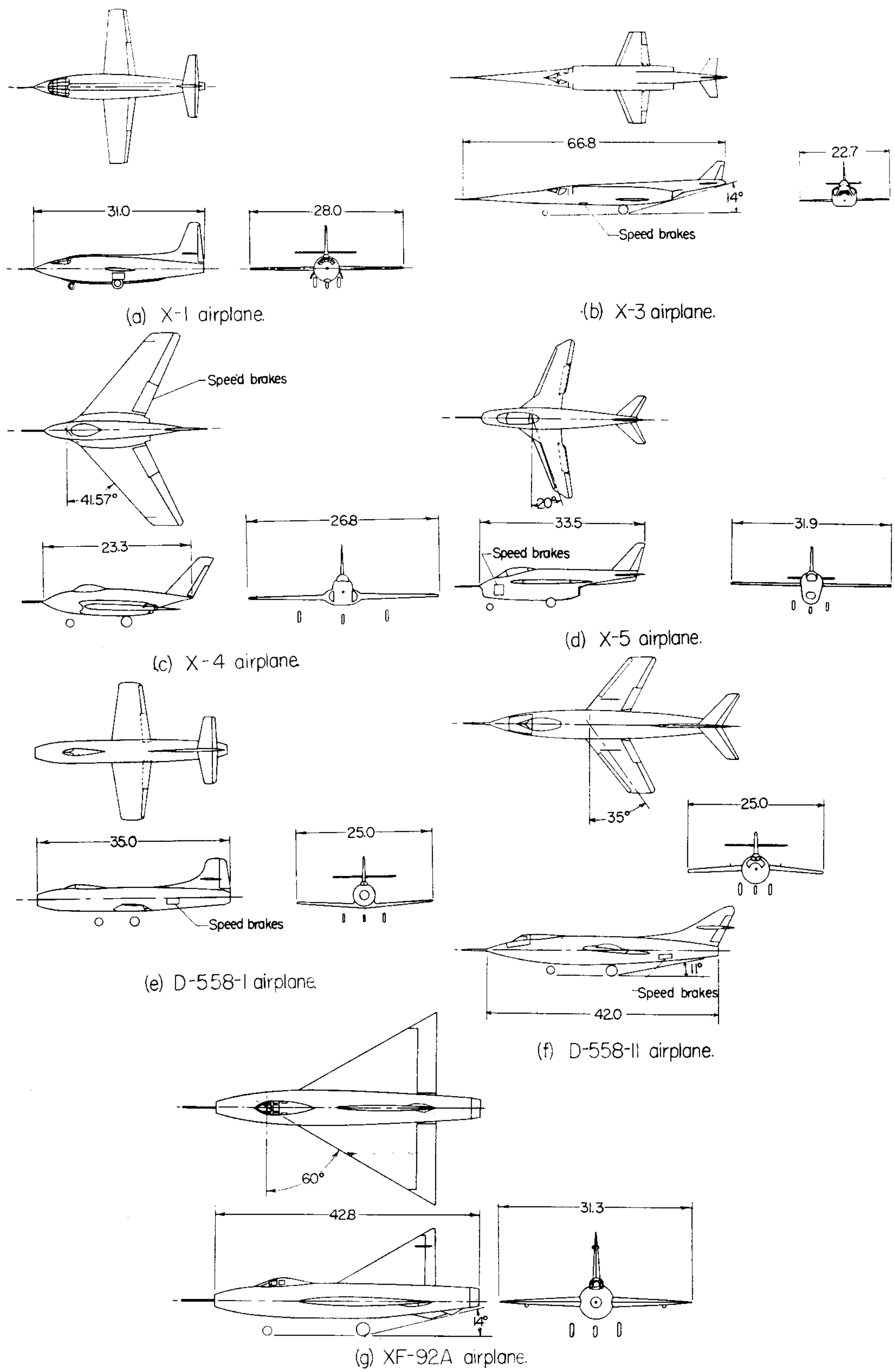
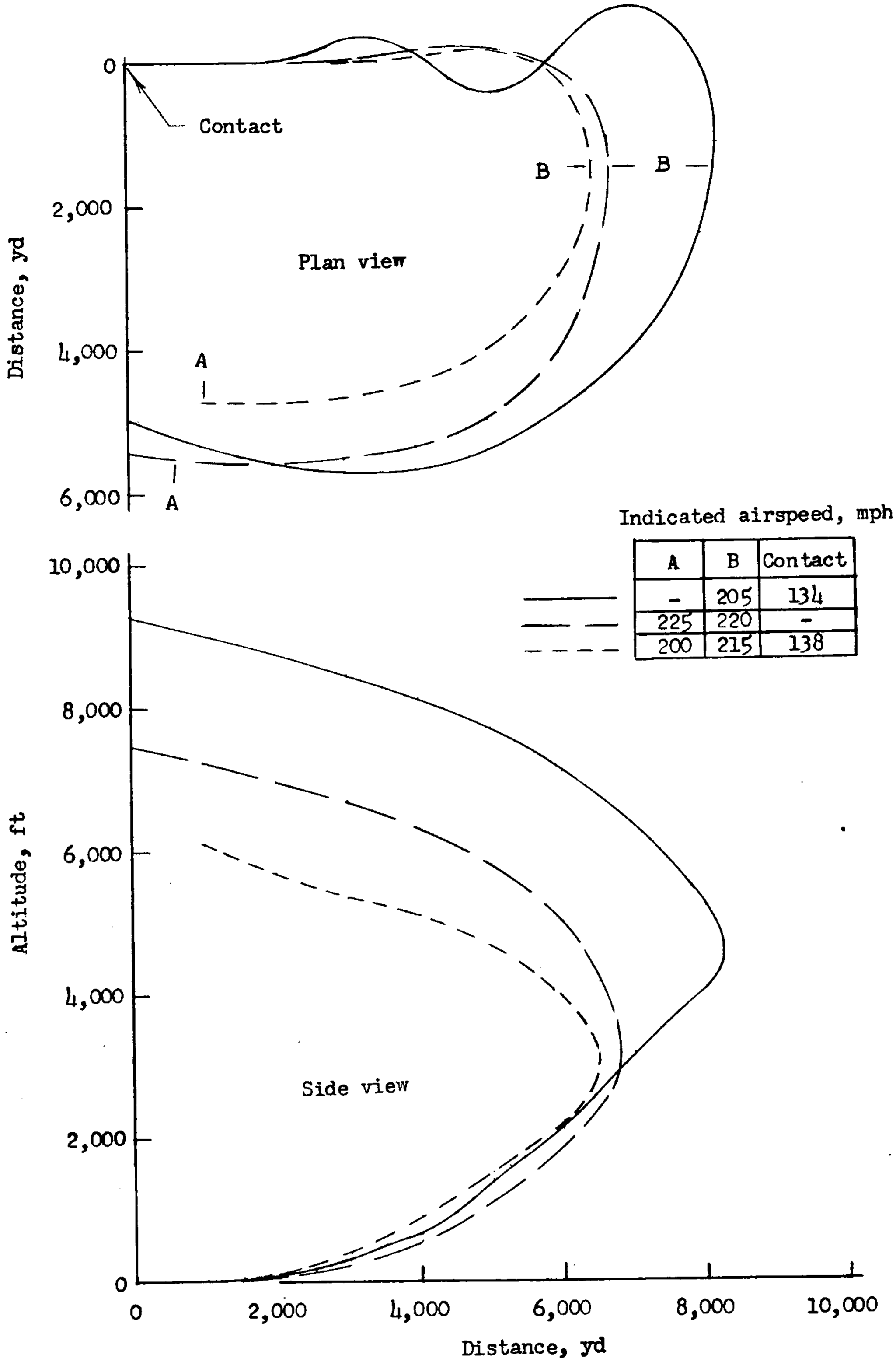


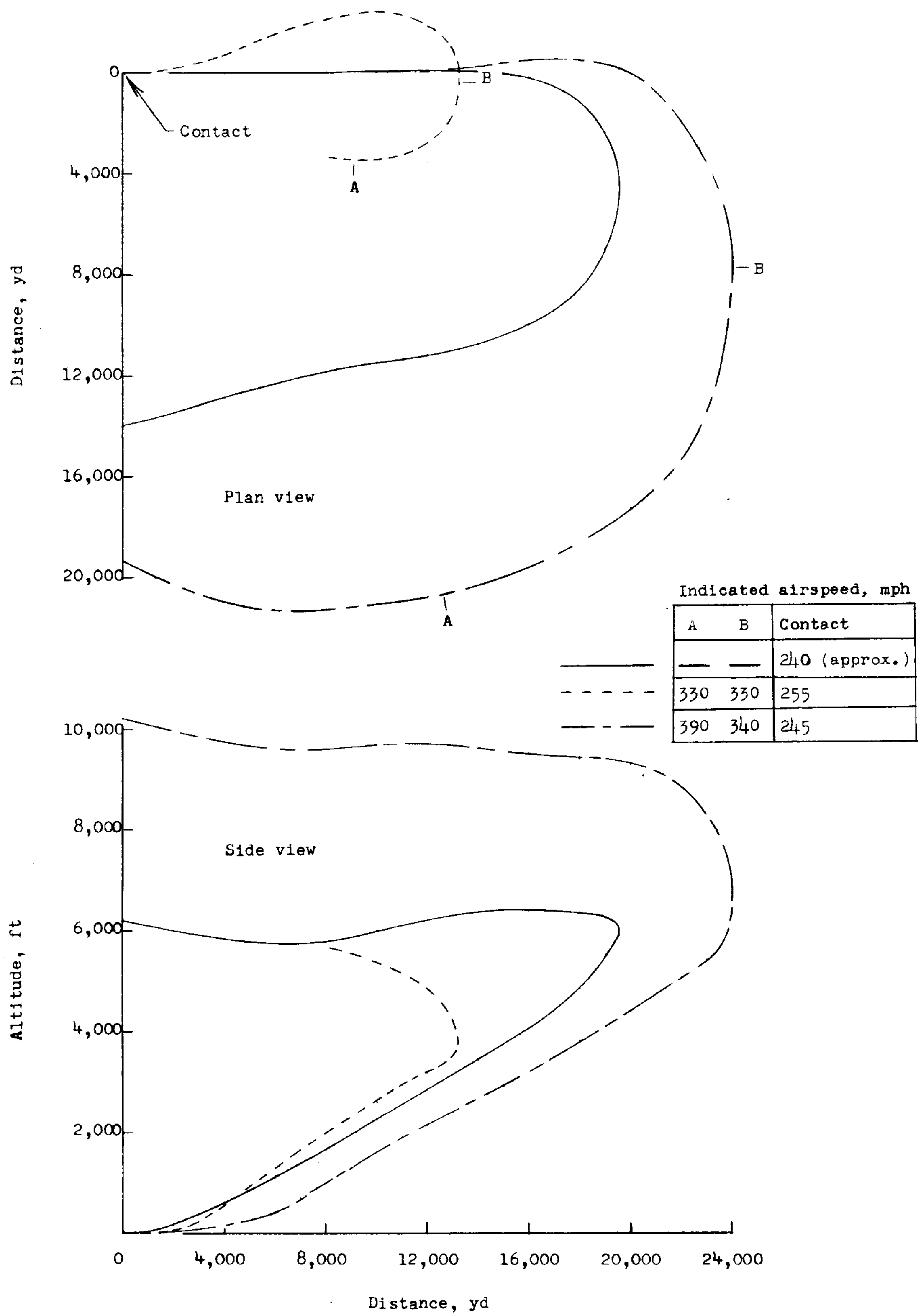
Figure 1.- Three-view drawings of the test airplanes. All dimensions in feet.



	A	B	Contact
(solid)	-	205	134
(long dash)	225	220	-
(short dash)	200	215	138

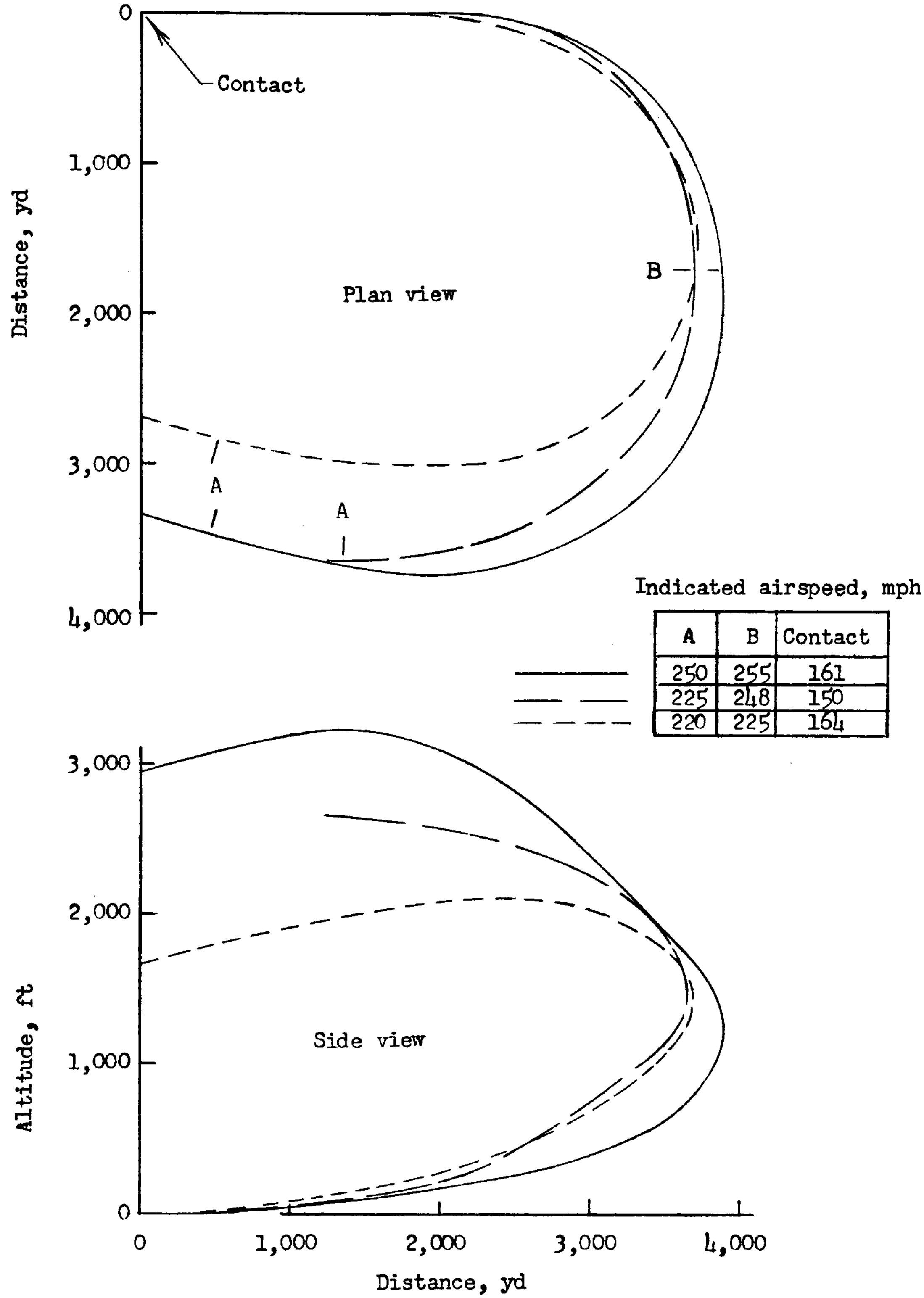
(a) X-1 glider airplane.

Figure 2.- Landing patterns for the test airplanes.



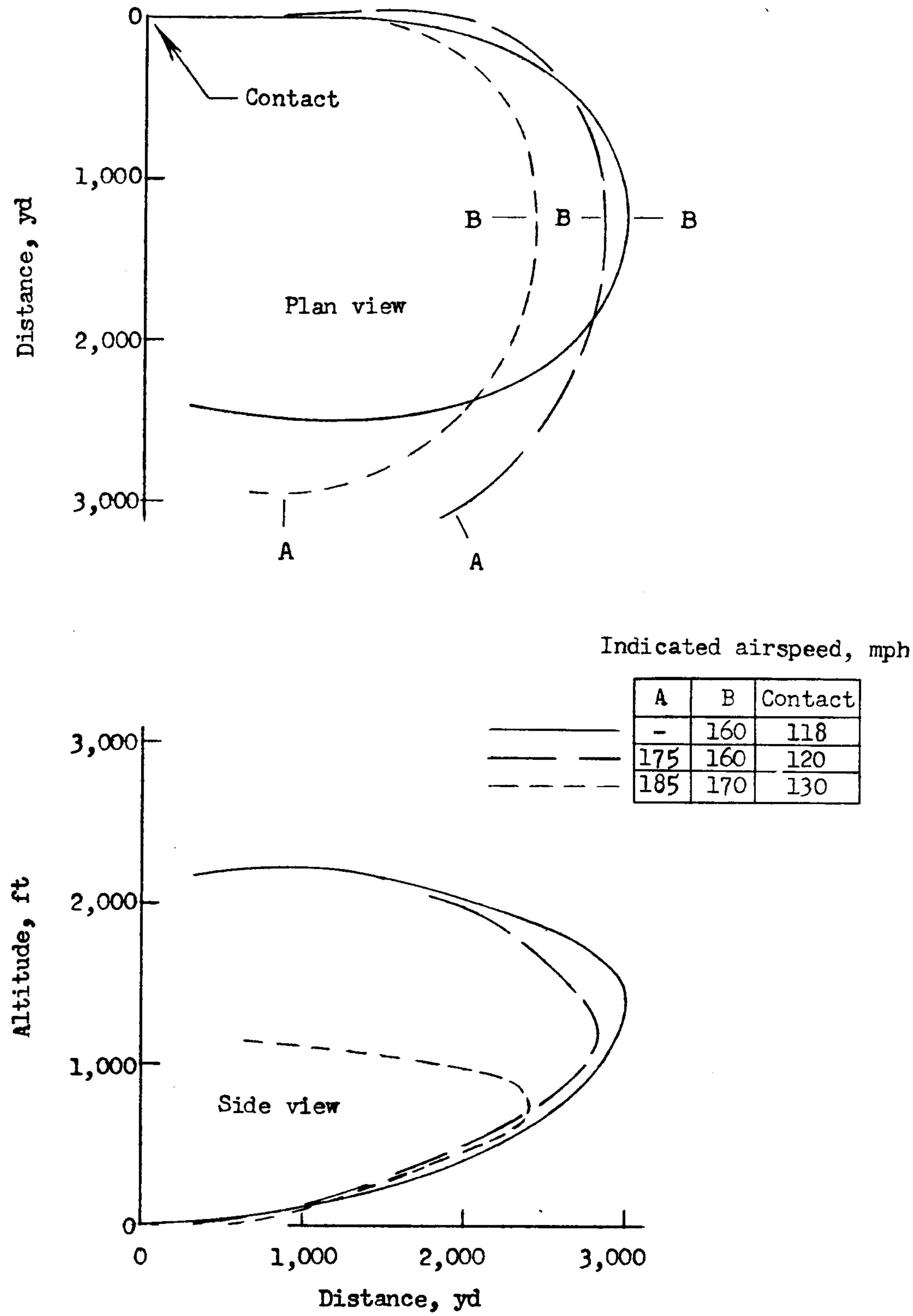
(b) X-3 airplane.

Figure 2.- Continued.



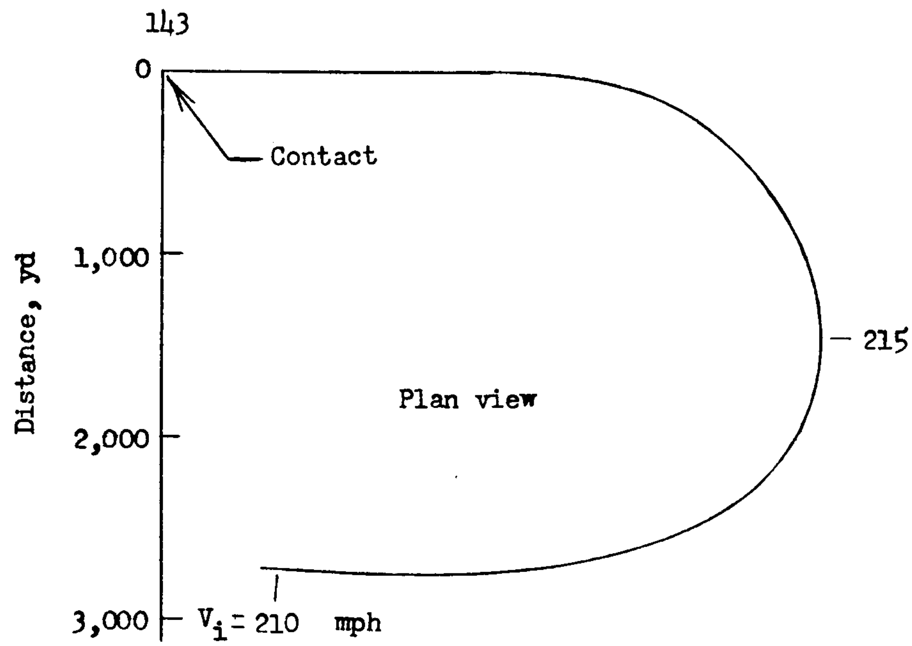
(c) X-4 airplane.

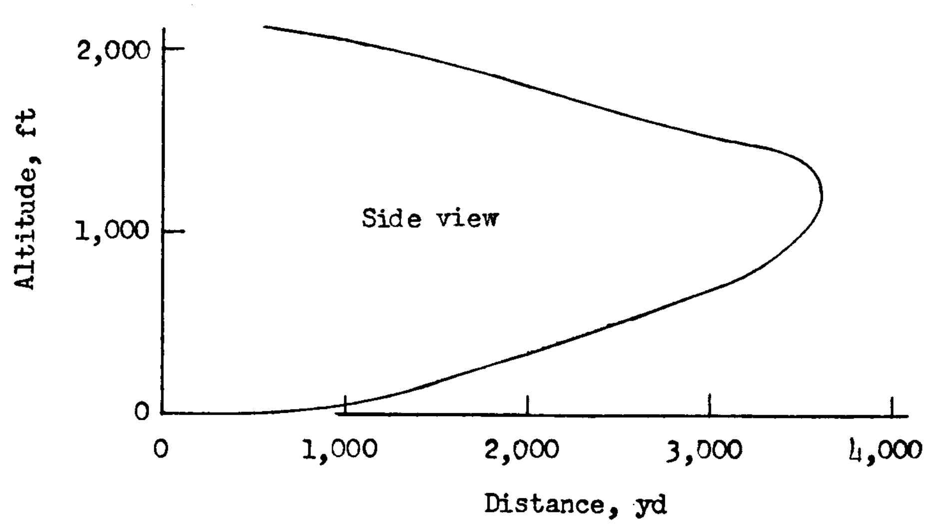
Figure 2.- Continued.



(d) X-5 airplane.

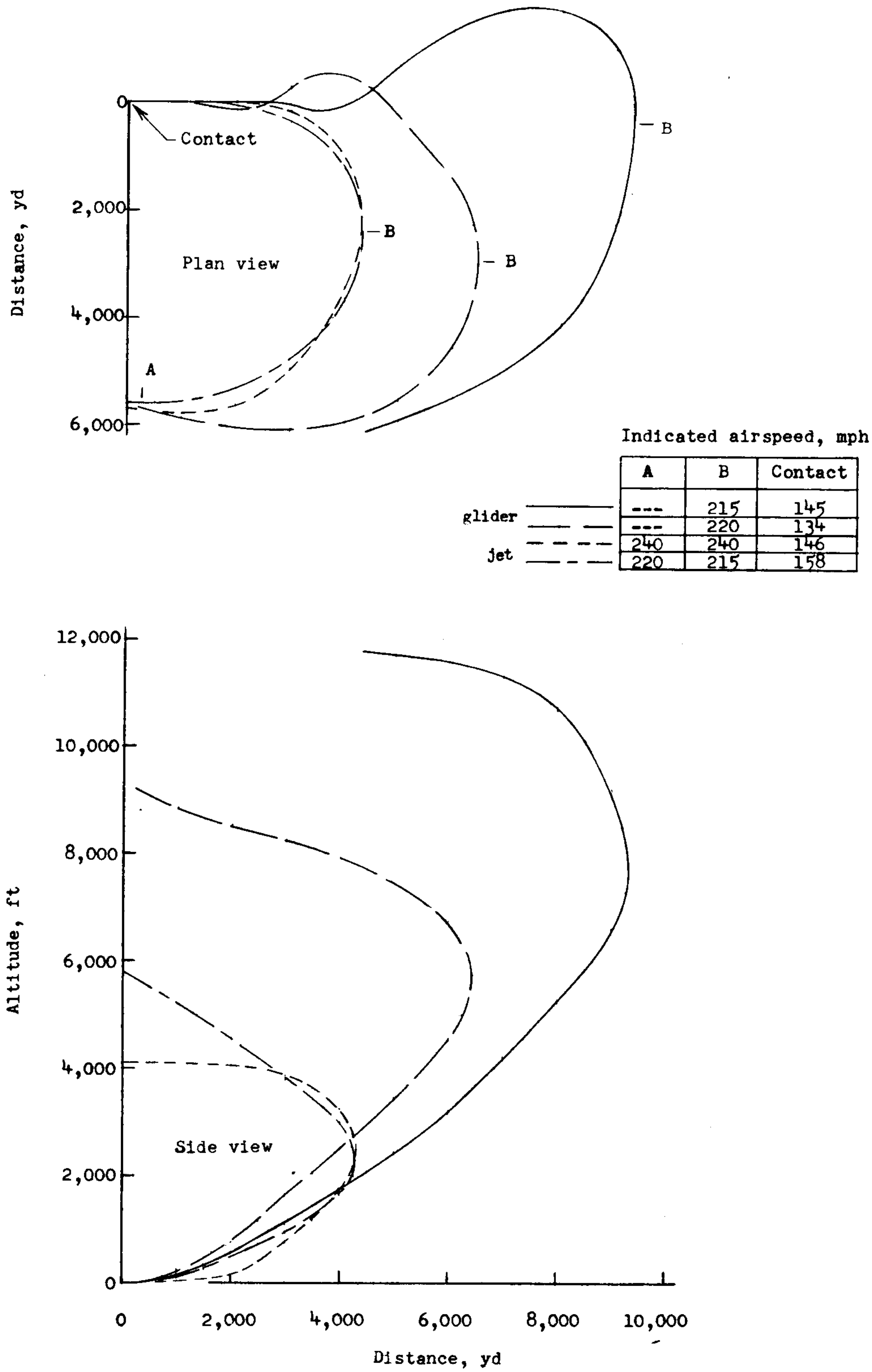
Figure 2.- Continued.





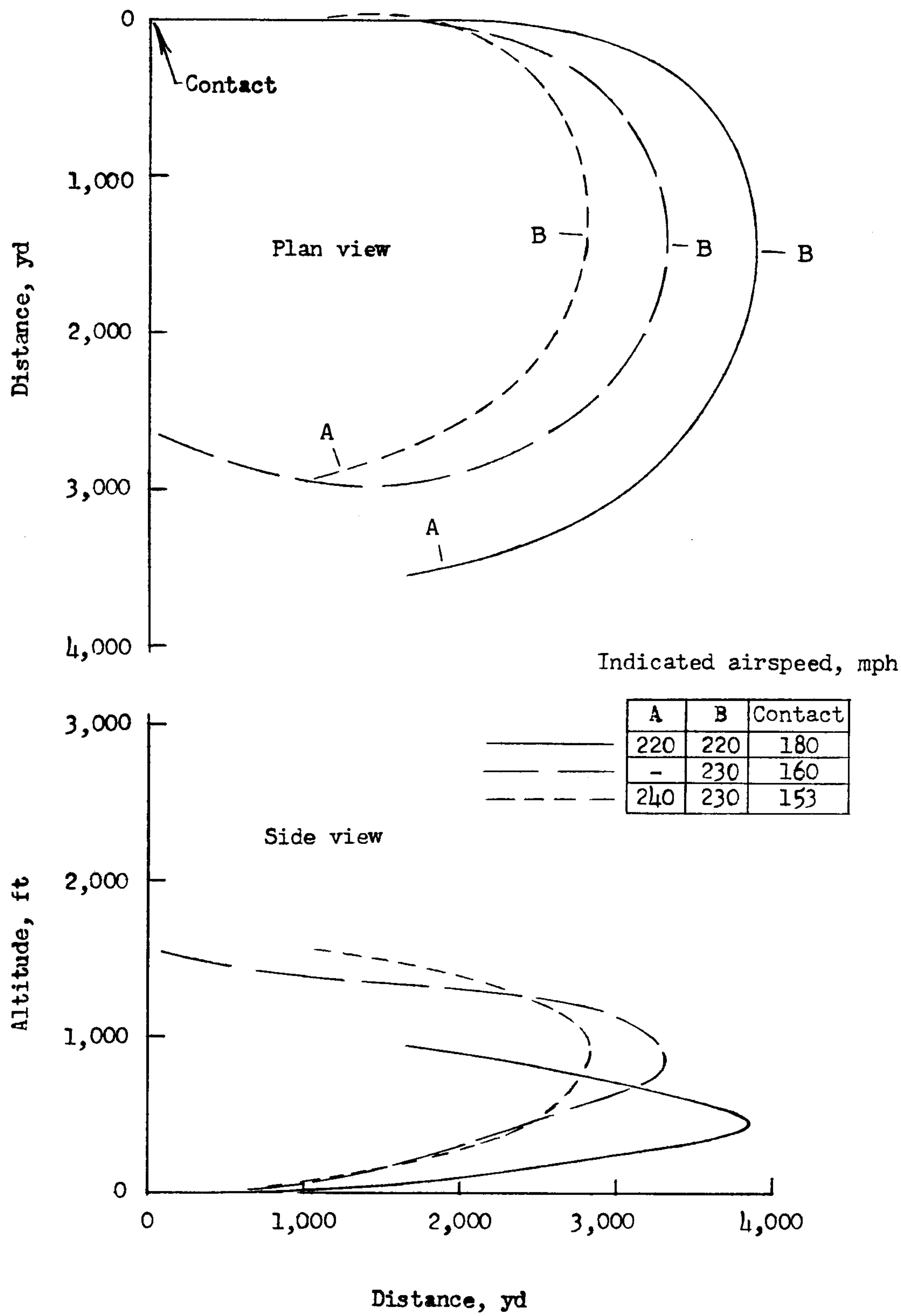
(e) D-558-I airplane.

Figure 2.- Continued.



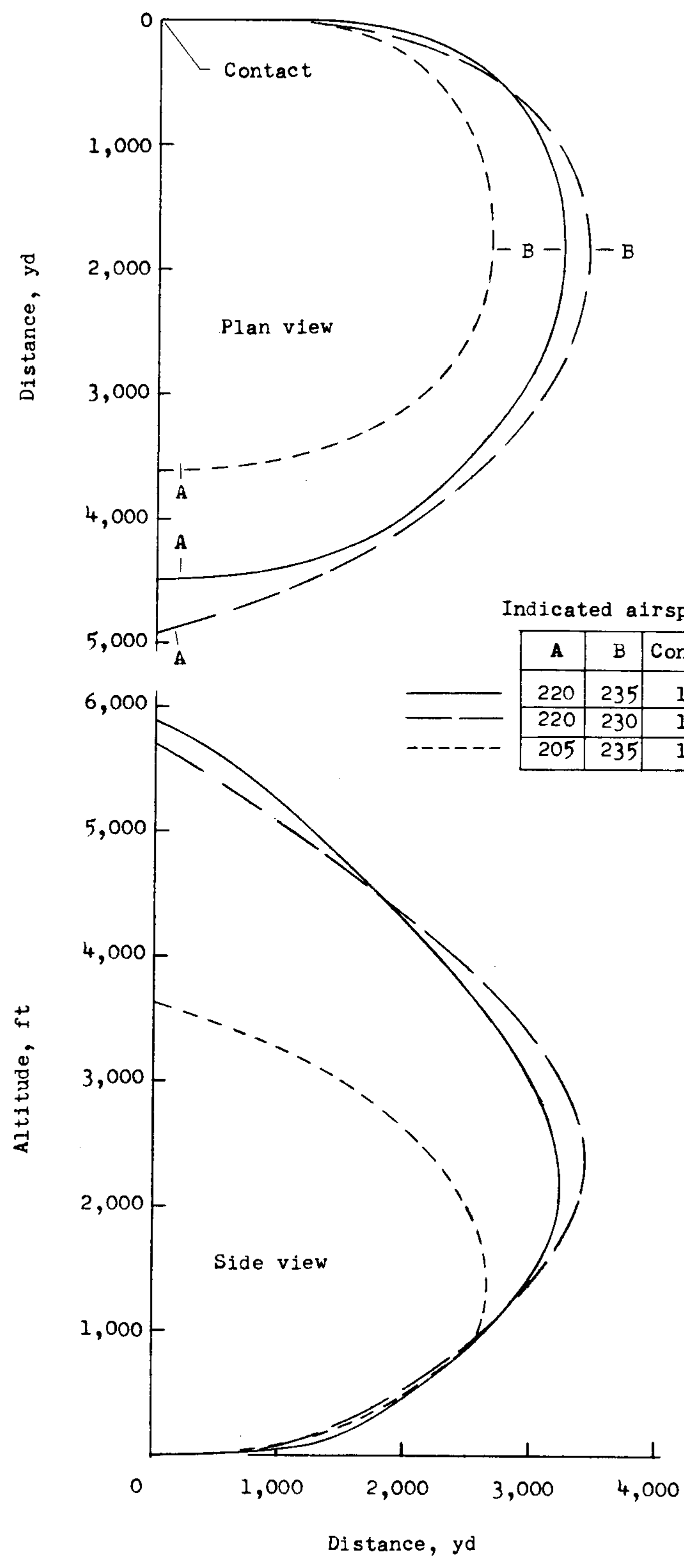
(f) D-558-II airplanes.

Figure 2.- Continued.



(g) XF-92A airplane.

Figure 2.- Continued.



	A	B	Contact
solid line	220	235	168
long dash	220	230	176
short dash	205	235	163

(h) XF-92A airplane, idle power.

Figure 2.- Concluded.

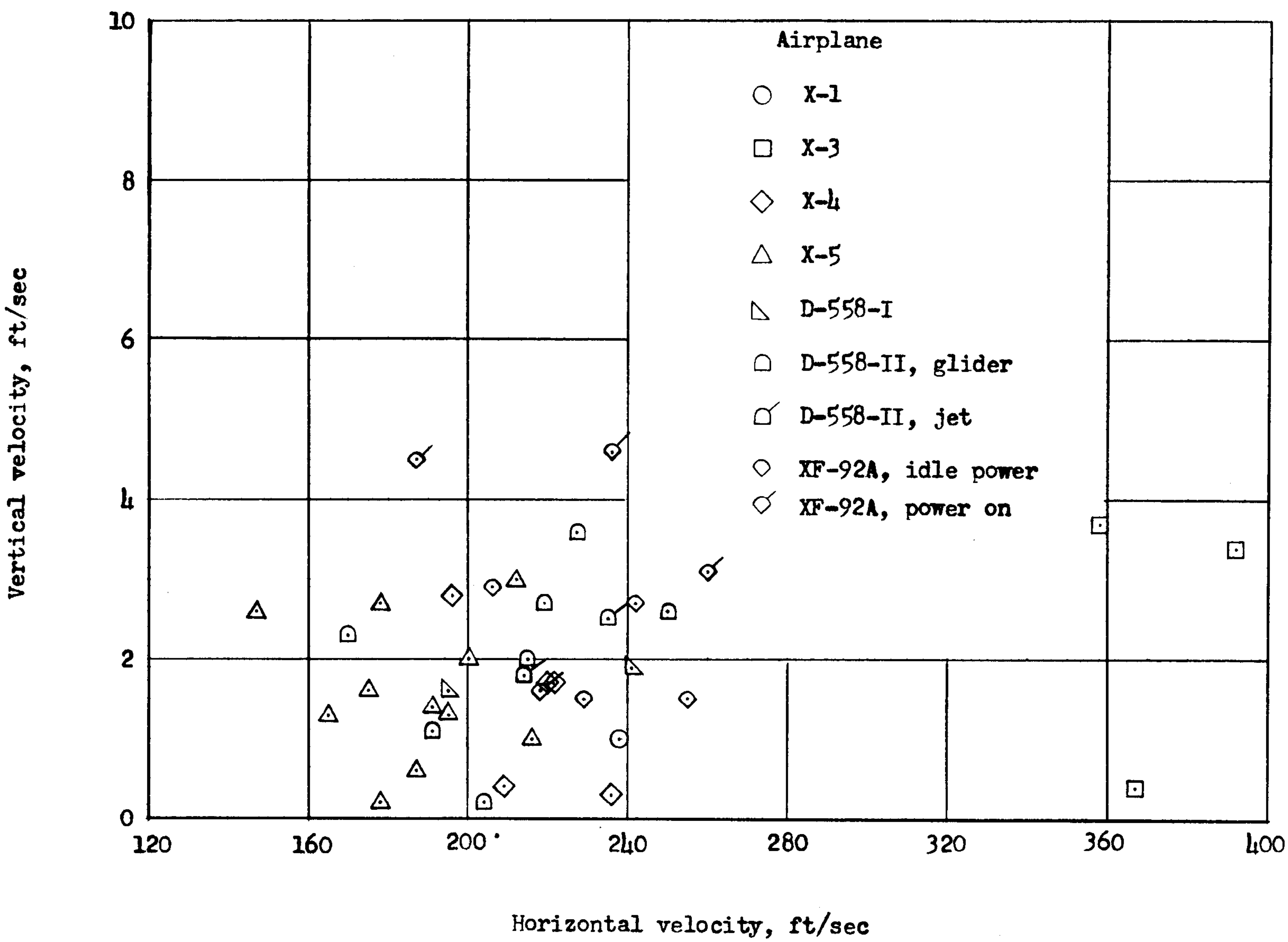


Figure 3.- Vertical and horizontal velocities at ground contact.

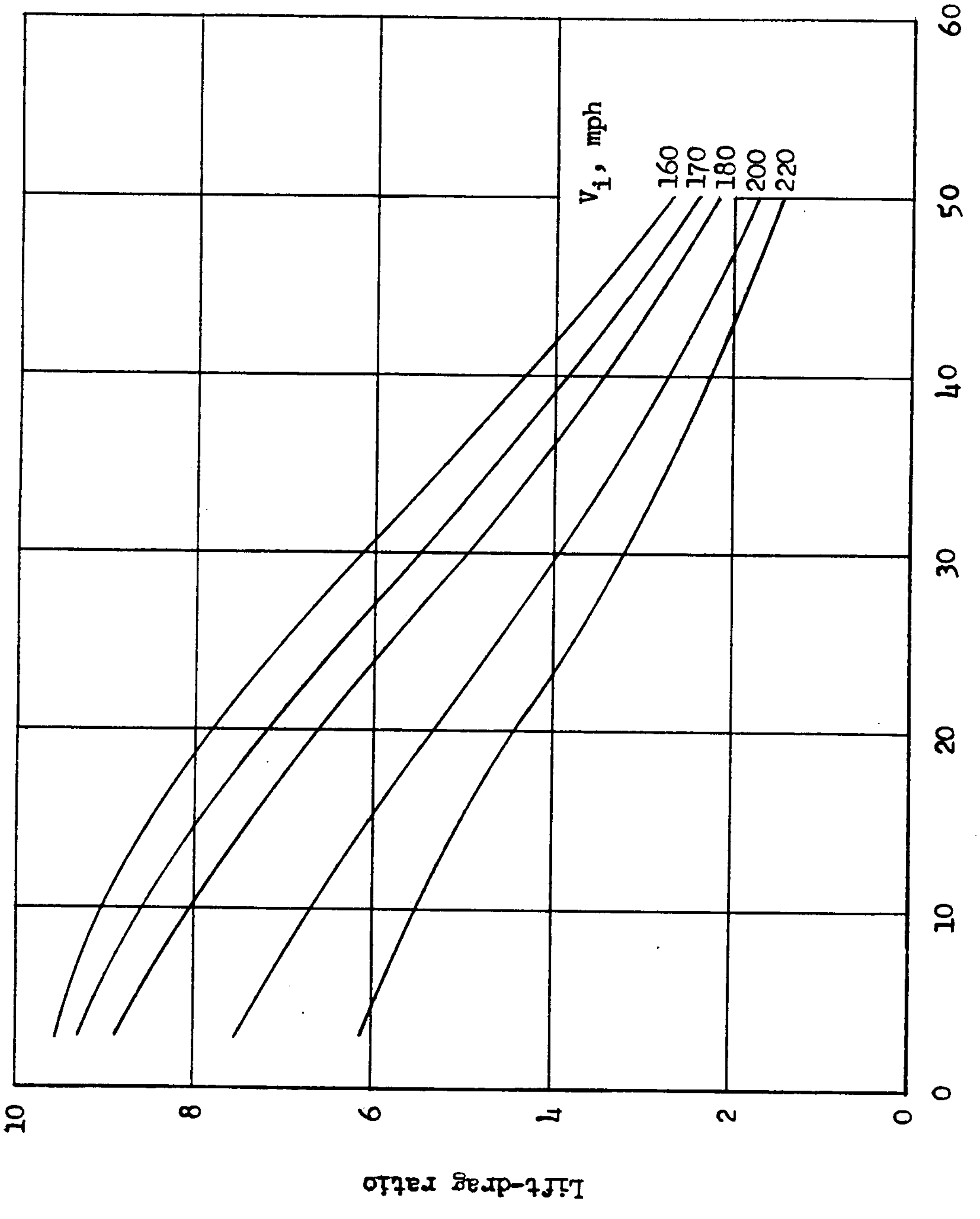


Figure 4.- Variation of lift-drag ratio with dive-brake position and indicated airspeed of the X-4 airplane.

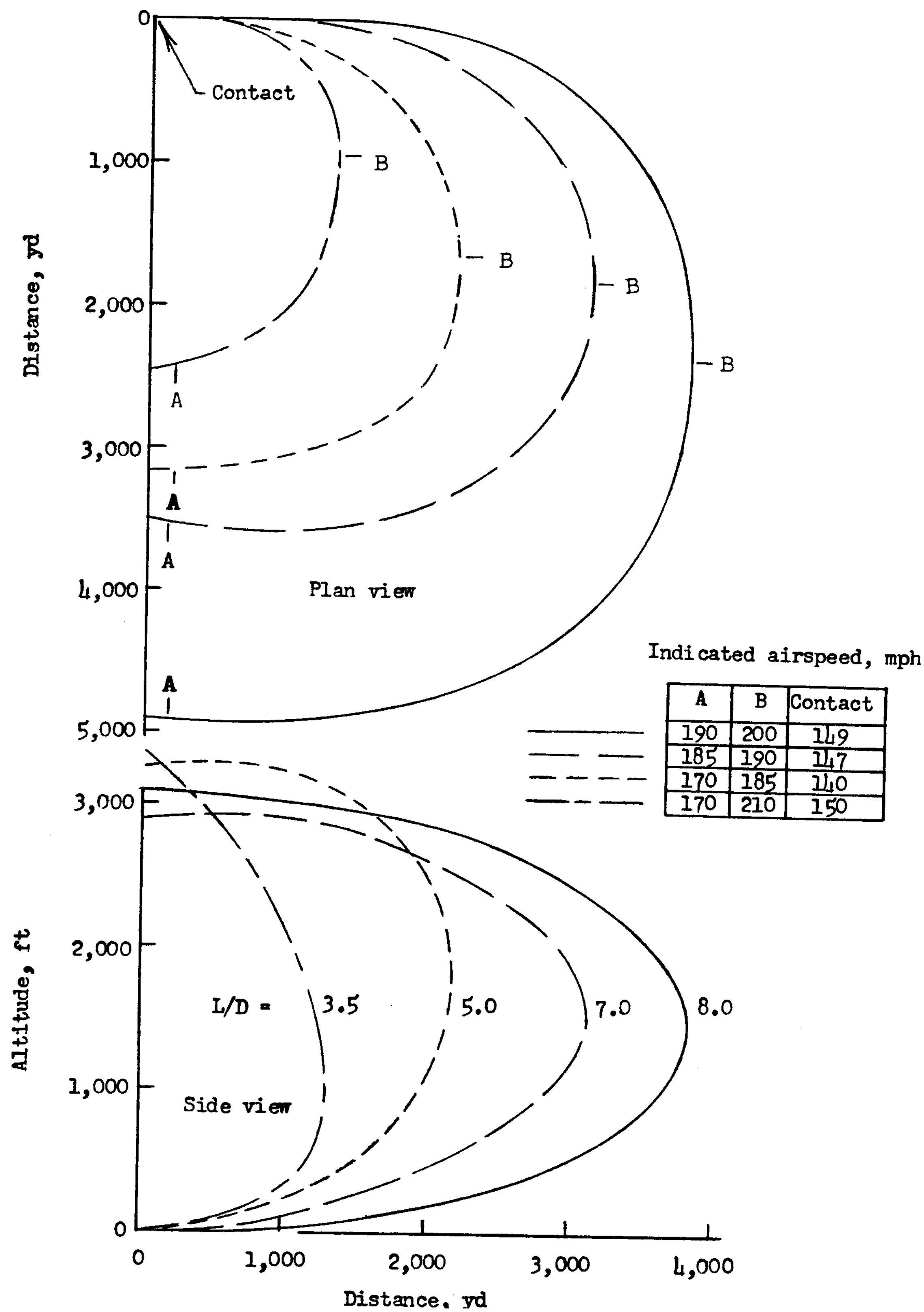


Figure 5.- Landing patterns at various lift-drag ratios for the X-4 airplane.

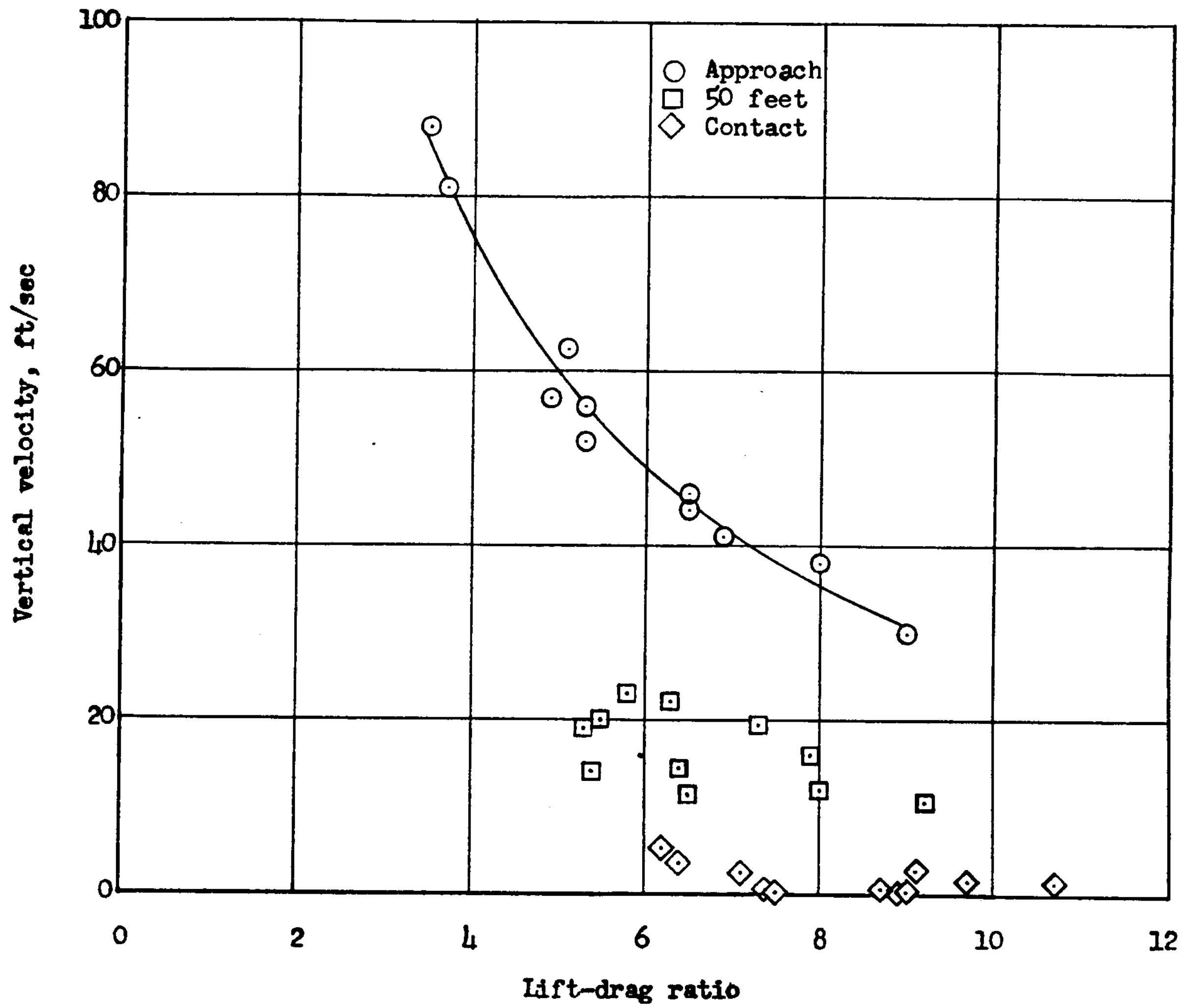


Figure 6.- Variation with lift-drag ratio of vertical velocity at three points during the landing of the X-4 airplane.